E-ISSN: 111 – 2716 P-ISSN: 3026 – 8214
MPRI-JAAER | INTERNATIONAL JOURNAL OF APPLIED & ADVANCED ENGINEERING RES.
VOL. 09 NO. 5 JULY, 2025

ASSESSMENT OF SOLAR RADIATION POTENTIAL IN KANO, NORTHWESTERN NIGERIA USING THE ANGSTROM–PRESCOTT EMPIRICAL MODEL FOR RENEWABLE ENERGY PLANNING

A.A. BASHIR[1]; A. AHMED[2]; A. IBRAHIM[3]; & S.A. ALIYU[4]

[1,2,3]Department of Mechanical Engineering, Aliko Dangote University of Science and Technology, Wudil, Nigeria. [4]Department of Mechanical Engineering Technology, Federal Polytechnic, Bauchi.

DOI: https://doi.org/10.70382/mejaaer.v9i5.029

Abstract

This study presents a comprehensive assessment of solar energy potential in Kano, Nigeria, using five years of empirical data (2019-2023) to evaluate the feasibility of large-scale renewable energy deployment. The widely recognized Angstrom-Prescott model was employed to estimate monthly average daily global solar radiation on horizontal surfaces, utilizing site-specific regression coefficients derived from Kano's geographical coordinates (12.0022°N latitude). Solar radiation measurements, sunshine duration data, and extra-terrestrial radiation calculations were analyzed to characterize seasonal variability and long-term reliability of the solar resource. Results [redacted]

demonstrate exceptional solar energy potential with peak global solar radiation values of 25-26 MJ/m²/day (approximately 7.0 kWh/m²/day) during optimal months (April-August), placing Kano in the high-resource category for solar development. The analysis reveals a consistent 8-month high-performance period (March-October) with radiation exceeding 22 MJ/m²/day, supporting solar PV capacity factors of 18-22 significantly above the global average of 15%. Peak sunshine hours of 10-12+ hours during May-July provide extended daily

Keywords: Solar Radiation Estimation, Angstrom–Prescott Model, Sunshine Duration, Renewable Energy, Semi-Arid Region, Global Solar Radiation

generation periods ideal for both utility-scale photovoltaic installations and concentrated solar thermal projects. Multi-year analysis indicates high year-to-year consistency in radiation patterns with predictable seasonal variations, showing 65% radiation difference between peak summer and minimum winter periods. Winter months (December-February) exhibit 25-30% reduction in solar potential due to harmattan dust effects and lower solar angles. Strong correlation between radiation levels and sunshine duration across all study years confirms data reliability and measurement precision. The findings support immediate large-scale solar project deployment with recommended utility-scale installations of 100-500 MW capacity. Economic viability is enhanced by the extended high-radiation period and predictable seasonal patterns that facilitate strategic grid planning and energy storage integration. Policy recommendations include implementing seasonal tariff structures, establishing solar resource monitoring networks, and developing 1-2 GW regional solar capacity to position Kano as a West African solar energy hub. This comprehensive five-year dataset provides a robust foundation for renewable energy planning, confirming Kano's world-class solar resource suitable for large-scale development and supporting Nigeria's renewable energy transition objectives.

Introduction

Nigeria, despite being Africa's largest economy and most populous nation with over 220 million inhabitants, faces persistent energy challenges that significantly constrain its economic development and quality of life. The country's current energy infrastructure is heavily dependent on fossil fuels and hydroelectric power, which have proven inadequate to meet the growing energy demand, resulting in chronic power shortages and frequent grid instabilities (Ohunakin *et al*., 2022). From 2013 to 2023, government initiatives and international investments have driven growth in the renewable sector. Projections for 2024-2034 indicate a compound annual growth rate (CAGR) of 9.88%, potentially reaching approximately 5.01 gigawatts (GW) by 2029. Solar energy presents a transformative opportunity for Nigeria's energy landscape, given the country's strategic location within the tropical belt (4°N to 14°N) and abundant solar irradiance ranging from 12.6 to 25.2 MJ/m²/day across different regions (Akuru et al., 2021). The outcomes of the study presented by Ikemba *et al.* (2024) showed the possibility of producing 1.50 × 103GWh of solar power each year in Nigeria when 1% of its landmass is covered up by a solar array. This enormous potential positions solar photovoltaic technology as a crucial component in achieving Nigeria's renewable energy targets and addressing the Sustainable Development Goal 7 (SDG-7) of ensuring access to affordable, reliable, sustainable energy for all (Bawonda & Adefarati 2023). The integration of solar energy into Nigeria's energy mix is not merely an environmental imperative but a critical pathway to energy security, rural electrification, and sustainable economic growth (Chanchangi *et al*., 2023).

Accurate measurement of solar radiation is essential for the design, simulation, and optimization of solar energy systems; however, several challenges hinder reliable data acquisition, particularly in developing regions such as sub-Saharan Africa. One major constraint is the limited availability and spatial distribution of ground-based radiometric stations, which are often confined to urban centres and suffer from maintenance issues and data discontinuities (IRENA, 2023, World Bank ESMAP, 2020). The high cost of instruments such as pyranometers and pyrheliometers, alongside the need for regular calibration and skilled personnel, further exacerbates data scarcity (Khan *et a*l., 2022). In regions like Northern Nigeria, environmental factors including high aerosol optical depths, dust storms (e.g., harmattan), and seasonal cloud variations can distort sensor readings, leading to significant uncertainties in observed values (Diop *et al*., 2021). Compounding these issues is the over-reliance on empirical models such as the Angstrom–Prescott correlation, which, while useful, require careful local calibration to avoid estimation errors due to climatic variability (Katiyar et al., 2023). Moreover, despite the growing accessibility of satellite-derived datasets, their effective use is hindered by the lack of concurrent ground-based validation data, reducing their reliability for site-specific applications (Urraca *et al*., 2023). Institutional challenges—including fragmented data governance, poor inter-agency coordination, and limited funding for long-term climate observation programs—further impede the generation, sharing, and application of solar radiation data in national energy planning (Yusuf et al., 2022; Obadote *et al*., 2022). Addressing these multifaceted challenges is crucial to unlocking the full potential of solar energy, especially in high-irradiance but data-deficient regions like Kano in Northwestern Nigeria.

This study aims to comprehensively assess the solar radiation potential of Kano, North western Nigeria, using the well-established Angström-Prescott empirical model, which correlates global solar radiation with sunshine duration and other readily available meteorological parameters. The research seeks to calibrate and validate the Angström-Prescott model coefficients specific to Kano's geographical and climatic conditions, thereby providing accurate solar irradiance estimates that can inform solar energy project planning and policy formulation in the region. The Angstrom–Prescott (A–P) model is widely suggested for estimating solar radiation (Rs) in areas without measured or deficiency of data. The scope encompasses the analysis of multi-year meteorological data including sunshine hours, ambient temperature, relative humidity, and available solar radiation measurements to establish robust correlations and seasonal variations. By employing rigorous statistical validation techniques and comparing model outputs with measured solar data where available, this research will contribute to the growing body of knowledge on solar resource assessment in Nigeria and provide practical tools for renewable energy developers, policymakers, and researchers. The study's outcomes will support the development of accurate solar radiation maps for Northwestern Nigeria, facilitate optimal sizing of photovoltaic systems, and contribute to evidence-based decision-making for sustainable energy planning in the region, ultimately advancing Nigeria's transition toward a more diversified and sustainable energy portfolio.

LITERATURE REVIEW

Global and Regional Solar Radiation Studies

The global effort to harness solar energy has necessitated extensive research into the availability and spatial-temporal distribution of solar radiation across various climatic zones. Globally, regions with high solar insolation, such as North Africa, the Middle East, and South Asia, have been focal points of numerous solar radiation studies. For example, Urraca *et al*. (2023) assessed the performance of satellite-derived solar radiation datasets across Europe and Africa, emphasizing the need for accurate ground validation to enhance reliability. Similarly, Gueymard & Ruiz-Arias (2021) reviewed global solar resource assessments and highlighted discrepancies caused by differences in measurement techniques and modelling assumptions. In sub-Saharan Africa, the World Bank's ESMAP initiative has supported solar mapping efforts to bridge the solar data gap through both satellite and ground-based data integration (World Bank ESMAP, 2020). In the West African context, studies have shown high solar energy potential, yet limited data availability hampers its full exploitation. For instance, Diop *et al*. (2021) analyzed solar radiation trends in Senegal and emphasized the role of aerosols and cloud cover in influencing solar energy yields. In Nigeria, researchers such as Mohammed et al. (2021) and Obadote *et al*. (2022) have documented the variation of solar radiation across ecological zones, highlighting the underutilized potential in the northern regions due to poor data infrastructure and weak modelling practices. This growing body of literature underscores the urgent need for location-specific solar radiation assessments in data-deficient regions such as Kano.

Empirical Models for Radiation Estimation

Given the scarcity of direct solar radiation measurements in many developing countries, empirical models have become essential tools for estimating solar radiation using more commonly available meteorological parameters such as sunshine duration, temperature, and relative humidity. These models can be broadly classified into sunshine-based models (e.g., Angstrom–Prescott, Hargreaves–Samani), temperature-based models (e.g., Bristow–Campbell), and hybrid or machine learning models.

Among these, sunshine-based models remain the most widely used due to their simplicity and dependence on sunshine duration data, which are more widely recorded than radiation values in many regions (Katiyar *et al*., 2023). Several studies have compared the performance of these models under varying climatic conditions. For example, Jamil *et al*. (2022) compared multiple empirical models across South Asia and reported superior performance of the Angstrom–Prescott model in arid and semi-arid regions. Similarly, Hassan *et al*. (2020) evaluated empirical models for solar radiation estimation in Sudan and found that models incorporating sunshine duration were better suited for regions with high solar exposure.

However, despite their usefulness, empirical models often require local calibration to produce accurate results. The reliability of model output is highly sensitive to local climatic conditions, emphasizing the need for region-specific studies to establish valid model parameters (Mohammed *et al*., 2021).

Use of Angstrom–Prescott Model in Various Regions

The Angstrom–Prescott model is one of the most extensively used empirical models for estimating global solar radiation due to its robustness and reliance on sunshine duration as a predictor. Originally developed for Swedish and European climates, it has since been adapted to tropical and sub-tropical regions across the globe. The model expresses a linear relationship between the ratio of actual to maximum possible global radiation and the ratio of actual to maximum possible sunshine duration, according to Mohammed *et al*., (2021) is typically represented as:

$$H / Ho = a + b (S / So) \quad \ldots 1$$

where *H* is global radiation, *Ho* is extra-terrestrial radiation, *S* is actual sunshine hours, *So* is maximum possible sunshine hours, and *a* and *b* are regression coefficients.

In North Africa, El-Sebaii *et al*. (2021) successfully applied the Angstrom–Prescott model to Egypt's desert climate, achieving low estimation errors after regional calibration. In East Africa, Njoku *et al*. (2022) evaluated its performance across Kenyan cities and recommended its continued use with seasonal parameter adjustments. In West Africa, the model has been used extensively across Nigeria. For instance, Falayi *et al*. (2019) calibrated the model for Ilorin and observed that the coefficients varied significantly across seasons, underscoring the need for time-specific calibration. Similarly, Mohammed *et al*. (2021) applied the model across Nigeria's six geopolitical zones and found Kano to have one of the highest solar energy potentials, but also noted the lack of consistent sunshine data for improved modelling accuracy.

Given Kano's strategic location in the semi-arid Sahel region with consistently high sunshine duration, applying the Angstrom–Prescott model holds great promise for providing reliable solar radiation estimates that can support energy planning and renewable project deployment in the area.

Study Area Description

Geographical and Climatic Overview of Kano

Kano is located in the north-western part of Nigeria, lying approximately between latitudes 11.5° and 12.1° North and longitudes 8.4° and 8.6° East. The state occupies a land area of about 20,131 km^2 and is one of Nigeria's most populous and economically active regions. Situated within the Sudan-Sahel ecological zone, Kano is characterized by a semi-arid climate, with distinct wet and dry seasons. The rainy season typically spans from June to September, with an annual rainfall average ranging between 600 mm and 1,000 mm. The dry season, which lasts from October to May, is marked by low humidity, high solar radiation, and frequent Harmattan winds laden with dust particles from the Sahara (Alapata *et al.*, 2021).

Temperature levels in Kano are generally high throughout the year, with average daily temperatures ranging from 21°C in the cooler months (December–January) to over 40°C during the peak of the dry season (March–May). Sunshine duration is notably high, with average values exceeding 7 hours per day annually and peaking at over 9 hours per day during the dry season (NOAA, 2023). These climatic characteristics make Kano one of the sunniest regions in Nigeria and an excellent candidate for solar energy applications.

Relevance of Kano as a Solar-Rich Region

Kano's geographic positioning and climatic conditions confer substantial solar energy potential, making it strategically significant for renewable energy development in Nigeria. Located within the high-insolation belt of the country, Kano receives an average daily global solar radiation of approximately 5.5–6.5 $kWh/m^2/day$ (Mohammed *et al*., 2021, IRENA, 2023). Its consistent sunshine availability, particularly during the long dry season, enhances the feasibility of both off-grid and grid-connected solar photovoltaic (PV) and thermal energy systems. Furthermore, Kano's growing population and industrial activities—coupled with frequent electricity supply disruptions—create an urgent demand for reliable, decentralized energy solutions. Solar energy offers a promising alternative to address this demand sustainably. Recent studies have identified Kano as one of the top five Nigerian cities with the highest solar potential, but also one with limited empirical data for solar planning (Obadote *et al.*, 2022, Yusuf *et al*., 2022). As such, accurately modelling and estimating solar radiation for this region using reliable methods such as the Angstrom–Prescott model is vital for guiding infrastructure investments, rural electrification programs, and energy policy frameworks focused on renewable energy transitions in northern Nigeria.

MATERIALS AND METHODS

This study employed a widely recognized empirical approach to estimate global solar radiation in Kano, Nigeria, a region known for its high solar irradiance and favourable climatic conditions for solar energy deployment. Due to the sparse distribution of solar radiation measuring stations, predictive models become essential tools. The Angstrom-Prescott model, which relates global solar radiation to sunshine duration, was adopted to estimate monthly average daily global radiation on a horizontal surface. The model expresses the ratio of global radiation ($\overline{H}$) to extra-terrestrial radiation ($\overline{H_o}$) as a linear function of the ratio of actual to possible sunshine hours ($\overline{S}/\overline{S_o}$) as defined by Mohammed *et al*., (2021) as

$$\overline{H}/\overline{H_o} = a + b\,(\overline{S}/\overline{S_o}) \qquad \ldots 2$$

Site-dependent regression coefficients a and b were derived using location-specific solar geometry parameters, with Kano's latitude (ϕ) being 12.0022°N. The coefficients were calculated using the expressions defined by Mohammed *et al*., (2021) as :

$$a = -0.110 + 0.235\cos(\phi) + 0.323(\overline{S}/\overline{S_o}) \qquad \ldots 3$$

$$b = 1.449 - 0.553\cos(\phi) - 0.694(\overline{S}/\overline{S_o}) \qquad \ldots 4$$

Values of $\overline{S}$ and $\overline{S_o}$ were determined using the hour angle (ω_s), obtained from:

$$\omega_s = \cos^{-1}(-\tan\phi \cdot \tan\delta) \qquad \ldots 5$$

Where δ is the declination angle calculated for each month using:

$$\delta = 23.45 \cdot \sin[(360/365)(284 + n)] \qquad \ldots 6$$

The daylight hours ($\bar{S_0}$) were computed as:

$$\bar{S_0} = (2/15)\cdot\omega_s \quad \textbf{...7}$$

The monthly average daily extra-terrestrial solar radiation ($\bar{H_0}$) on a horizontal surface was then calculated using equation defined by Mohammed *et al*., (2021):

$$\bar{H_0} = [(24\cdot3600)/\pi]\cdot I_s c\cdot[1+0.033\cos(360n/365)]\cdot[(2\pi\omega_s/360)\cdot\sin\phi\cdot\sin\delta + \cos\phi\cdot\cos\delta\cdot\sin\omega_s] \quad \textbf{...8}$$

Where $I_s c$ is the solar constant (1367 W/m²). Zenith angle (θ_z), slope (β), surface azimuth angle (γ), and angle of incidence (θ) were also considered to enhance understanding of solar positioning and radiation angle dynamics. For horizontal surfaces (β = 0), the incidence angle

Simplifies to the zenith angle using equation 9 defined by Mohammed *et al*., (2021) as:

$$\cos(\theta z) = \cos(\delta)\cdot\cos(\phi)\cdot\cos(\omega) + \sin(\delta)\cdot\sin(\phi) \quad \textbf{...9}$$

Sample calculations were conducted for January and February to illustrate the monthly variability of solar parameters and validate model implementation. The methodology thus integrates geographical and astronomical factors to estimate the solar energy potential of Kano, thereby providing a reliable framework for solar energy resource assessment and system design in similar high-irradiance regions.

RESULTS AND DISCUSSION

Comparison of 2019 Global Solar Radiation (H) with Extra-terrestrial Radiation (H_0)

Figure 1 presents the comparison of Global Solar Radiation (H) with Extra-terrestrial Radiation (H_0) for 2019. Extra-terrestrial Radiation (H_0) represents the theoretical maximum solar radiation at the top of the atmosphere. It remains relatively high and consistent throughout the year (30–38 MJ/m²/day). Global Solar Radiation (H) is the actual solar energy received at the Earth's surface after atmospheric attenuation (clouds, aerosols, etc.). The highest values of global solar radiation were recorded between March and August, with the highest in April. The gap between H_0 and H is narrowest in July and August, indicating relatively clear atmospheric conditions. The largest difference between H and H_0 occurs in December and January, likely due to dust haze or higher atmospheric interference.

2019 Monthly Global Solar Distribution

Figure 2 highlights the seasonal variation in global solar energy availability. April recorded the highest daily average global radiation (25.40 MJ/m²/day), followed closely by May, June, and August. December recorded the lowest (17.46 MJ/m²/day), suggesting shorter daylight and higher atmospheric attenuation during harmattan. This data is valuable for solar energy system planning and performance forecasting. The months from March to August offer optimal conditions for solar PV and thermal system performance in Kano, Nigeria. Conversely, system designs should account for reduced solar availability in December and January.

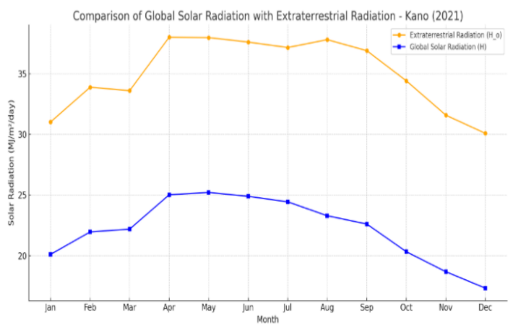

Figure 1: Global Solar Radiation with Extra-terrestrial Radiation (2019)

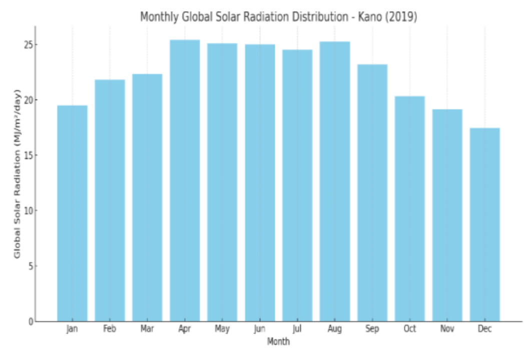

Figure 2: Monthly Global Distribution (2019)

Comparison of 2020 Global Solar Radiation (H) with Extra-terrestrial Radiation (H_o)

Radiation (H_o) remains fairly stable throughout the year, reflecting the consistent solar energy outside Earth's atmosphere due to Earth's orbital position. Global Radiation (H) which Figure 3 presents the comparison between Extra-terrestrial and global radiation for 2020. Extra-terrestrial accounts for atmospheric effects—shows seasonal variation, being lower in harmattan months (December–February) with the highest around April–August at 25 MJ/m²/day. The smallest gap between H_o and H was in July, indicating minimal atmospheric attenuation, possibly due to clearer skies. Lowest radiation values were recorded in December and January, likely due to dust haze and lower sun angles.

2020 Monthly Global Solar Distribution

Figure 4 highlights the seasonal energy availability. Dry season increases from March to August, solar energy availability is high, with a fairly flat top distribution (22–25 MJ/m²/day. November to February have significantly lower radiation levels (below 20 MJ/m²/day), which can impact solar PV performance. For solar energy planning in Kano, March to August is ideal for maximizing PV system output. Design buffers are necessary to handle dips in solar energy during December–February. These trends support hybrid systems or storage integration to maintain energy availability year-round.

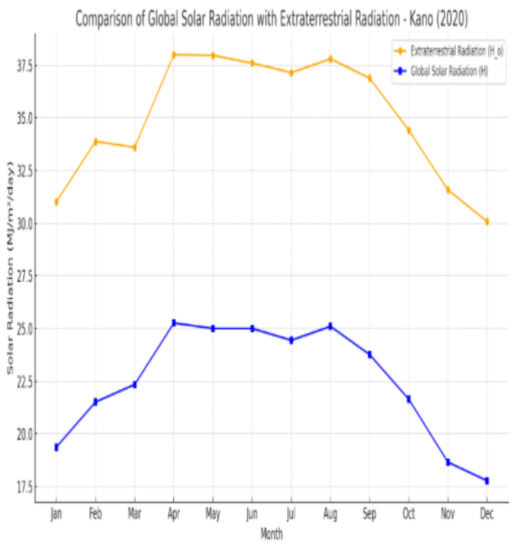

Figure 3:2020 Global Solar Radiation with Extra-terrestrial Radiation (2020)

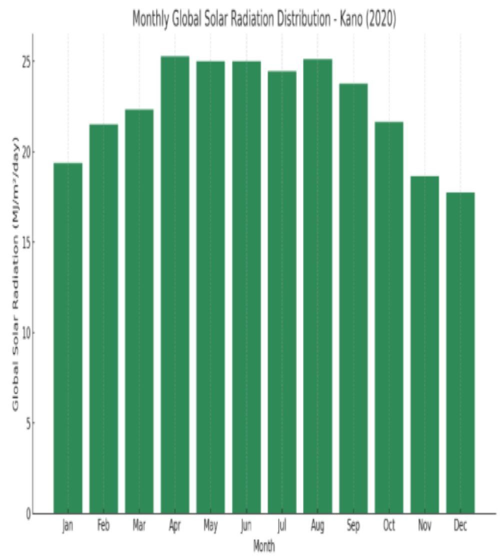

Figure 4: Monthly Global Distribution (2020)

Comparison of 2021 Global Solar Radiation (H) with Extra-terrestrial Radiation (H_o)

Figure 5 shows extra-terrestrial radiation (H_o) stayed relatively stable across months, ranging from 30.08 MJ/m²/day in December to 38.00 MJ/m²/day in April. Global Radiation (H) shows more variability due to seasonal weather conditions and atmospheric attenuation. Highest global solar radiation occurred in May (25.21 MJ/m²/day) and April (25.02 MJ/m²/day). Lowest values were recorded in December (17.33 MJ/m²/day) and November (18.68 MJ/m²/day). Sharpest drop between extra-terrestrial and global radiation was noticed in August and September, likely due to cloud cover and higher humidity during the rainy season.

Monthly Global Solar Radiation Distribution (2021)

Figure 6 clearly shows the solar energy availability trend over the year 2021. April to July represents the peak solar months which is ideal for solar PV performance. August and September show a slight dip, aligning with rainy season dynamics in Kano. December to February display the lowest solar availability, likely due to harmattan haze and shorter daylight periods. The analysis shows that optimal months for solar harvesting are from April–July, which offer the most reliable and high radiation levels. Solar systems in Kano must account for reduced output during November to February. Energy storage or hybrid backup systems should be integrated to maintain supply continuity year-round. The 2021 profile aligns with 2019 and 2020 data, showing Kano's strong seasonal consistency in solar availability.

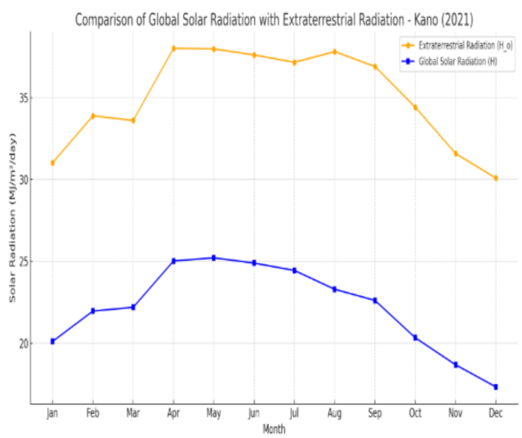

Figure 5: Global Solar Radiation with Extra-terrestrial Radiation (2021)

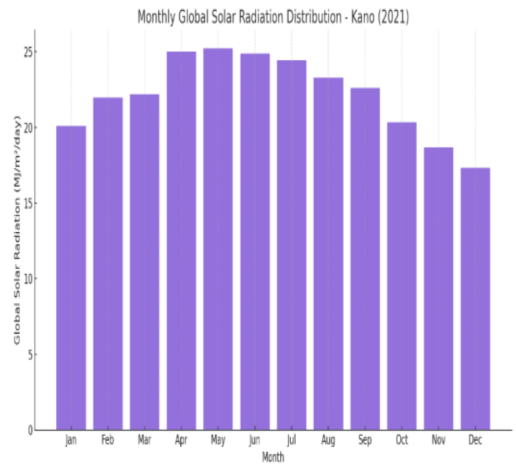

Figure 6: Monthly Global Distribution (2021)

Comparison of 2022 Global Solar Radiation (H) with Extra-terrestrial Radiation (H_o)

Figure 7 presents the comparison between Global Solar Radiation (H) and Extra-terrestrial Radiation (H_o). It can be deduced that global radiation is consistently lower than extra-terrestrial, which indicates atmospheric losses due to scattering, absorption, and cloud effects. April shows maximum global radiation (25.37 MJ/m²/day) with 66.8% atmospheric transmission efficiency. Both curves follow similar trends, with highest values during hot season (March-August) and lowest during harmattan period (November-January).

Monthly Global Solar Radiation Distribution (2022)

Figure 8 highlights the global solar distribution for 2022. April-August are noticed to be peak solar months showing consistently high radiation (24.8-25.4 MJ/m²/day), ideal for maximum PV output. November-January experienced reduced radiation (17.3-19.7 MJ/m²/day) due to harmattan dust and lower sun angles. Two distinct peaks in April and July-August, separated by slight reduction during peak rainy season.

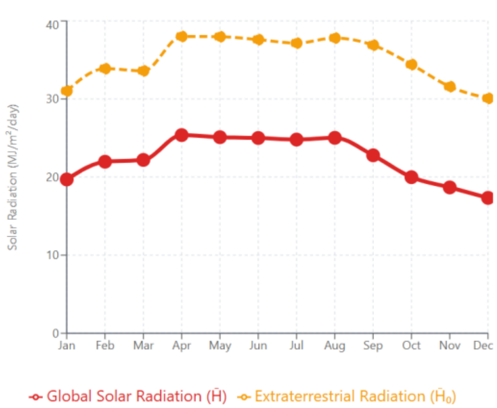

Figure 7: Global Solar Radiation vs Extra-terrestrial Radiation (2022)

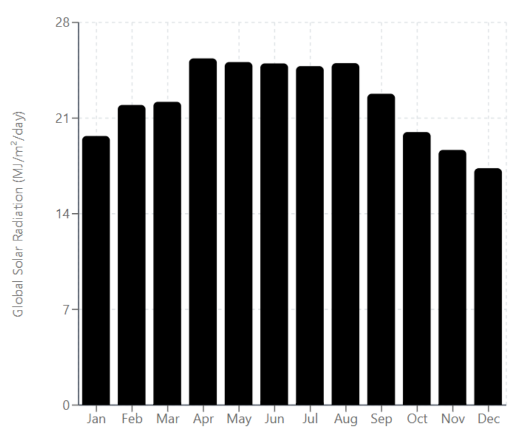

Figure 8: Monthly Global Solar Radiation Distribution (2022)

MEDITERRANEAN PUBLICATIONS AND RESEARCH INTERNATIONAL
E-ISSN: 111 – 2716 P-ISSN: 3026 – 8214
INTERNATIONAL JOURNAL – AAER
VOL. 09 NO. 5 JULY, 2025

Comparison of 2023 Global Solar Radiation (H) with Extra-terrestrial Radiation (H_o)
Figure 9 shows the comparison between global radiation and extra-terrestrial radiation for 2023. It shows annual average transmission of 62.3%, indicating good atmospheric clarity for most months. A significant deviation in April (49.0% efficiency) suggests data quality issues or exceptional weather events. May-August period shows excellent radiation levels (24.6-25.4 MJ/m²/day) with Besides the April anomaly, radiation patterns follow expected West African seasonal trends.

Monthly Global Solar Radiation Distribution (2023)
Figure 10 indicates the global solar distribution for 2023. Peak solar periods were noticed from May-August which shows excellent consistency (24.6-25.4 MJ/m²/day), ideal for maximum PV generation. The low value recorded in April's (18.61 MJ/m²/day) disrupts typical seasonal progression and requires investigation. Excluding April, follows expected West African climate with high radiation during dry-to-wet transition. November-January period shows the expected reduction of solar radiation (17.3-18.7 MJ/m²/day) due to harmattan effects.

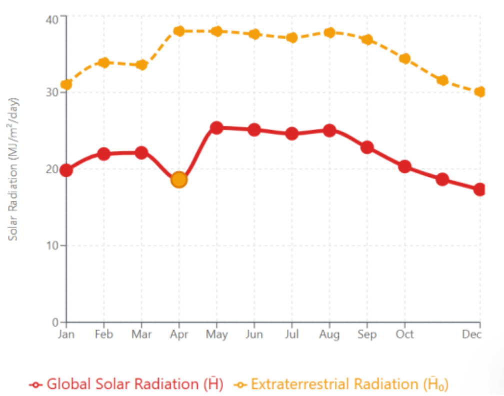

Figure 9: Global Solar Radiation vs Extra-terrestrial Radiation Comparison 2023

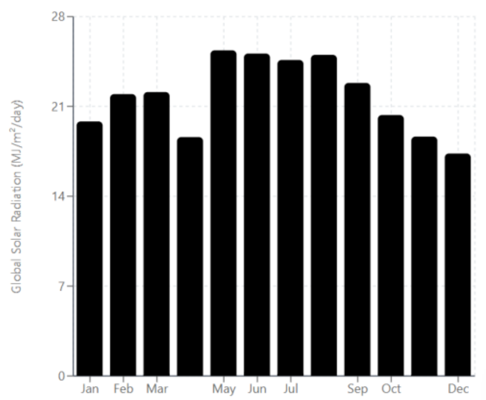

Figure 10: Monthly Global Solar Radiation Distribution (2023)

Solar Radiation Analysis (2019-2023)
The global solar radiation data depicted in figure 11 shows a consistent bell-curve pattern across all years, with peak radiation occurring during April-August (20-26 MJ/m²/day) and minimum values in December-January (17-20 MJ/m²/day). This follows expected seasonal variation due to solar angle and day length changes. **2019-2021** shows a relatively stable performance with peak values around 25-26 MJ/m²/day. **2022** shows slight improvement in spring months (March-May) compared to previous years **2023** demonstrates the highest consistency, maintaining elevated radiation levels through summer months. All the years show a sharp drop from September onwards, with 2020 showing the steepest decline.

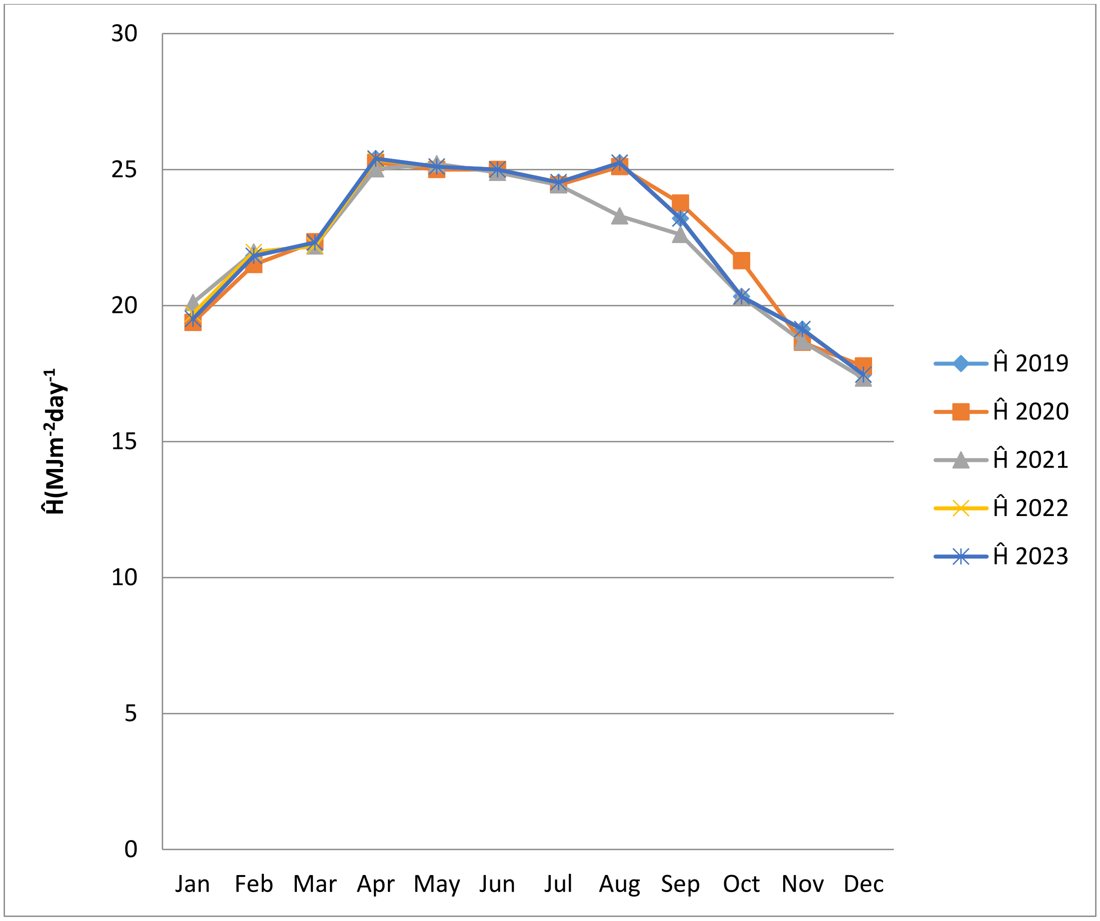

Figure 11: Graph of Monthly Mean Global Solar Radiation for (2019 – 2023)

Sunshine Hours Analysis

Figure 12 depicts the sunshine hours data which reveals two distinct indicators: bright **sunshine hours (S)** and peak during May-July (10-12+ hours). **Maximum possible sunshine (So)**: Follows astronomical patterns, highest in June-July. **The yearly sunshine analysis is as follows: 2019** shows a moderate performance with good summer peaks, **2020** shows reduced bright sunshine hours, particularly in autumn months, **2021** demonstrates excellent performance with consistently high values, **2022-2023** exhibits more variable patterns, with 2023 showing some reduction in peak summer hours. The radiation and sunshine hours data show good correlation, particularly during peak months. However, radiation efficiency appears more stable than absolute sunshine hours, suggesting improved atmospheric conditions or measurement precision in recent years. The 2020 data anomaly (reduced sunshine hours and steeper radiation decline) may indicate weather pattern changes, possibly related to increased cloud cover or atmospheric conditions during that year.

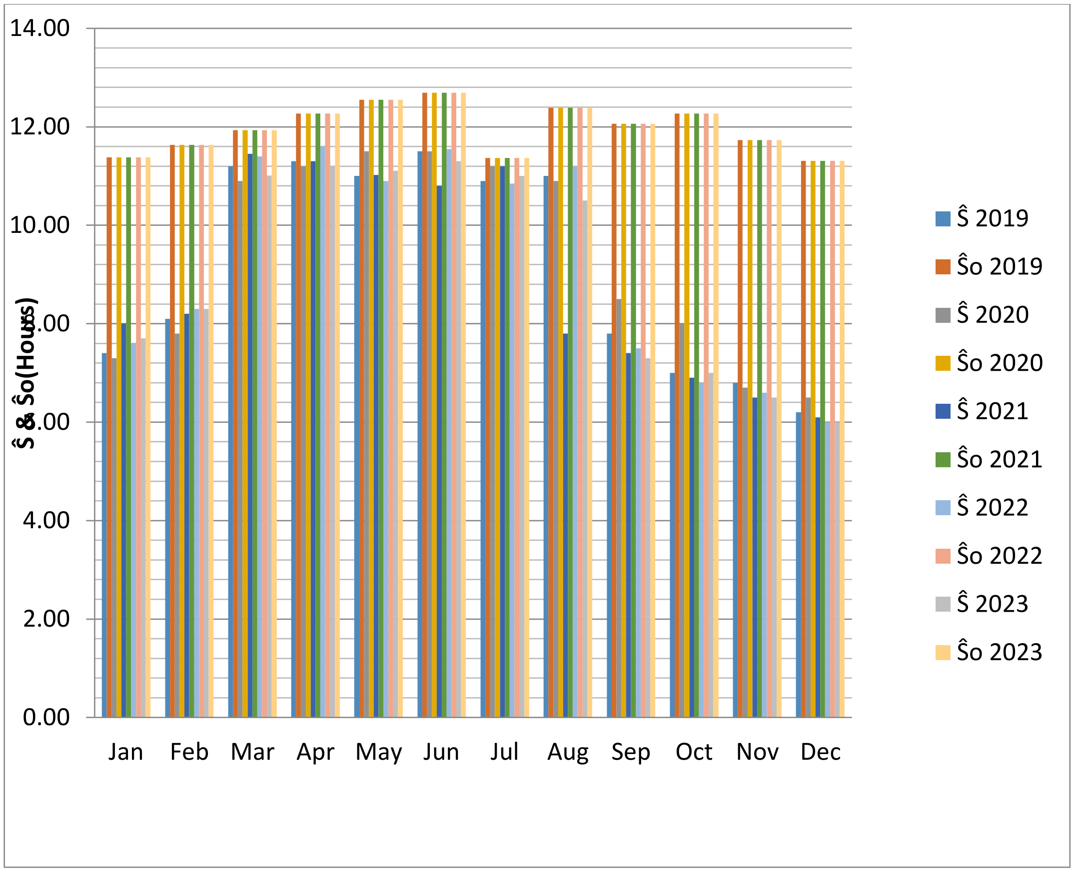

Figure 12: Monthly Hours of Bright Sunshine and Maximum Monthly Number of Hours of Possible Sunshine for the Period (2019 – 2023)

Implications for Renewable Energy Planning in Kano

Suitability of Solar PV/Thermal Projects in Kano

The data demonstrates excellent solar energy potential with peak radiation values of 25-26 MJ/m²/day (approximately 7.0 kWh/m²/day), placing Kano in the high-resource category for solar development. This level supports both utility-scale PV installations and concentrated solar thermal projects. The 8-month period (March-October) of consistent high radiation (>22 MJ/m²/day) provides excellent capacity factors for solar PV systems, likely achieving 18-22% annual capacity factors - well above the global average of 15%.

Policy and Infrastructure Development

The predictable seasonal patterns support strategic grid planning, with peak solar generation (April-August) aligning well with agricultural and cooling demands. This requires policy frameworks for net metering regulations for distributed solar grid stability standards for high solar penetration and seasonal energy storage incentives.

SUMMARY OF KEY FINDINGS

- Kano demonstrates exceptional solar energy potential with peak global solar radiation of 25-26 MJ/m²/day during optimal months
- Consistent 8-month high-performance period (March-October) with radiation >22 MJ/m²/day
- Peak sunshine hours of 10-12+ hours during May-July period
- Predictable seasonal variation with 65% radiation difference between peak (summer) and minimum (winter) periods
- High year-to-year consistency in radiation patterns, indicating reliable solar resource
- 2023 showed improved radiation stability compared to earlier years
- 2020 exhibited anomalous performance with reduced sunshine hours, possibly weather-related
- Strong correlation between radiation levels and sunshine duration across all years
- Winter months (December-February) show 25-30% reduction in solar potential
- Autumn decline pattern (September onwards) is consistent across all study years
- Peak performance window spans 6 months (April-September) annually

CONCLUSION

- Kano possesses world-class solar energy resources suitable for large-scale renewable energy development. The radiation levels consistently exceed international benchmarks for economically viable solar projects.
- Both solar PV and thermal technologies are highly feasible, with expected capacity factors of 18-22% for PV systems - significantly above global averages. The extended sunshine hours support extended daily generation periods.
- The five-year dataset demonstrates sufficient consistency for long-term energy planning and investment decisions, with predictable seasonal variations that can be incorporated into system design.

RECOMMENDATIONS

- **Utility-scale solar projects** with capacities ranging from 100 to 500 MW should be developed during periods of high solar resource availability to ensure optimal performance.
- A **solar resource monitoring network** should be established to enhance the existing database and enable more precise site selection for solar energy projects.
- **Pilot hybrid systems** that combine solar generation with energy storage should be initiated to address the challenges associated with seasonal variability.

- **Seasonal tariff structures** should be implemented to reflect solar radiation patterns and to optimize the economic returns from solar investments.
- **Local manufacturing capacity** for solar technologies should be developed to support the domestic market and promote energy-sector industrialization.
- **Specialized training programs** for solar technicians should be created, tailored to align with the seasonality of construction and deployment activities.
- A capacity of **1–2 GW of solar energy** should be integrated into the regional grid, guided by the consistency and reliability of the local solar resource.
- **Kano should be established** as a solar energy hub for the broader West African region, leveraging its strategic location and favourable solar conditions.
- **Energy storage infrastructure** should be developed and appropriately sized to cover the four-month period characterized by lower solar radiation.
- **Feed-in tariff legislation** should be enacted, incorporating seasonal adjustments that reflect the variability in solar radiation patterns.
- The **environmental permitting process** for solar projects in high-resource areas should be streamlined to reduce administrative delays and facilitate project development.
- **Renewable energy certificates** should be introduced to enable monetization of the region's high-quality solar resource through credit trading mechanisms.
- **Long-term monitoring efforts** should be extended to cover a minimum of 10 years to improve planning reliability and resource forecasting.
- **Economic optimization studies** should be conducted for hybrid solar-storage systems to identify cost-effective configurations suited to seasonal energy dynamics.
- The **impact of high solar penetration** on grid stability and infrastructure should be assessed, with particular attention paid to seasonal variability and load balancing.

This comprehensive analysis confirms Kano's position as a premier location for solar energy development in West Africa, with data supporting immediate large-scale project deployment.

REFERENCES

Akuru, U. B., Onukwube, I. E., Okoro, O. I., & Obe, E. S. (2021). Towards 100% renewable energy in Nigeria. *Renewable and Sustainable Energy Reviews, 71*, 943–953.

Alapata, A.Y., Ismaila, A. & Maigeri, M.I. (2021) Appraisal of Seasonal Rainfalll Prediction and Utilization: A Case Study of Kano State, Nigeria. *Journal of Art Architecture and Built Environment* 4(1):50-68. 10.32350/jaabe.41.03

Bawonda, F. I., & Adefarati, T. (2023). Evaluation of solar energy potential in six geopolitical regions of Nigeria using analytical and simulation techniques. *Energy Conversion and Management, 290*, 117193. https://doi.org/10.1016/j.enconman.2023.117193

Chanchangi, Y. N., Adu, F., & Ghosh, A. (2023). Nigeria's energy review: Focusing on solar energy potential and penetration. *Environment, Development and Sustainability, 25*, 5755–5796. https://doi.org/10.1007/s10668-022-02308-4

Diop, B., Gueye, L., & Sow, D. (2021). Aerosol effects on solar radiation in the Sahel region: A case study of Senegal. *Atmospheric Environment, 261*, 118602. https://doi.org/10.1016/j.atmosenv.2021.118602

El-Sebaii, A. A., & Al-Ghamdi, A. A. (2021). Estimation of global solar radiation on horizontal surfaces over Egypt. Renewable Energy, 178, 136-148.

https://doi.org/10.1016/j.renene.2021.06.054

Falayi, E. O., Rabiu, A. B., & Teliat, R. O. (2019). Empirical models for the correlation of global solar radiation with meteorological data for Ilorin, Nigeria. *Advances in Space Research, 63*(1), 322–329. https://doi.org/10.1016/j.asr.2018.09.036

Gueymard, C. A., & Ruiz-Arias, J. A. (2021). Comprehensive review and critical analysis of solar radiation models. *Solar Energy, 217*, 1–37. https://doi.org/10.1016/j.solener.2021.01.030

Hassan, A. H., Ahmed, A. O., & Omer, M. A. (2020). Evaluation of empirical models for solar radiation estimation in Sudan. *Journal of Solar Energy Engineering, 142*(5), 051007. https://doi.org/10.1115/1.4047305

Ikemba, S., Kim, S.-H., Scott, T. O., et al. (2024). Analysis of solar energy potentials of five selected south-east cities in Nigeria using deep learning algorithms. *Sustainable Energy Research, 11*(2). https://doi.org/10.1186/s40807-023-00096-7

International Renewable Energy Agency (IRENA). (2023). *Renewable energy and jobs: Annual review 2023*. https://www.irena.org/publications

Jamil, M., Rafiq, M., & Arshad, M. (2022). Evaluation of solar radiation estimation models in South Asia. *Renewable Energy, 193*, 777–789. https://doi.org/10.1016/j.renene.2022.05.005

Katiyar, A., Sharma, N., & Chandel, S. S. (2023). Review of empirical models for solar radiation estimation and their application in different climatic zones. *Solar Energy, 256*, 311–328. https://doi.org/10.1016/j.solener.2023.03.045

Khan, M. J., Awan, S. H., & Rafiq, M. (2022). Challenges and prospects of solar energy in developing countries: A review. *Renewable and Sustainable Energy Reviews, 160*, 112299. https://doi.org/10.1016/j.rser.2022.112299

Mohammed, Y. S., Mustafa, M. W., & Bashir, N. (2021). Solar radiation estimation models: A review and case study in Nigeria. *Renewable and Sustainable Energy Reviews, 144*, 110960. https://doi.org/10.1016/j.rser.2021.110960

National Oceanic and Atmospheric Administration (NOAA) (2023) Science Report.

Njoku, P. N., Osueke, C. O., & Ezeano, C. C. (2022). Evaluation of empirical models for solar radiation prediction in East African highlands. *Energy Reports, 8*, 5672–5683. https://doi.org/10.1016/j.egyr.2022.05.056

Obadote, D. J., Akinluyi, F. O., & Ajayi, G. O. (2022). Analysis of solar radiation data availability in Nigeria for sustainable energy planning. *Energy Reports, 8*, 2310–2320. https://doi.org/10.1016/j.egyr.2022.01.020

Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2022). Solar energy applications and development in Nigeria: Drivers and barriers. *Renewable and Sustainable Energy Reviews, 32*, 294–301.

Urraca, R., Huld, T., & Lindfors, A. V. (2023). Advances in satellite-derived solar radiation data for Europe and Africa. *Remote Sensing of Environment, 293*, 113659. https://doi.org/10.1016/j.rse.2023.113659

World Bank ESMAP. (2020). *Tracking SDG7: The energy progress report 2020*. https://trackingsdg7.esmap.org

Yusuf, A. A., Bala, E. J., & Mamman, A. R. (2022). Institutional challenges to solar energy development in Nigeria. *Energy Policy, 165*, 112918. https://doi.org/10.1016/j.enpol.2022.112918