A Survey On The Assessment Of Solar Energy Potential In Nigeria

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Abstract: This study assesses the solar energy potential of Nigeria using global solar radiation data of forty-seven (47) locations obtained from the NASA meteorological database over a period of forty-one (41) year. The results show that the overall monthly average global solar radiation and the annual average ranges from 3.19 to 6.99 kWh/m²/day, and 4.20 and 6.14 kWh/m²/day, respectively. Three distinctive zones of solar radiation levels are identified in Nigeria. Higher solar radiation levels are observed in the arid northern region compared to the southern region, with greater intensities recorded during the dry season than the rainy season. April and August are identified as the months with the highest and lowest solar radiation levels, respectively. The spatial distribution of solar radiation across Nigeria indicates substantial potential for solar energy harvesting using flat-plate solar collectors.

Keywords: Nigeria, renewable energy, solar collector, solar energy, solar radiation,

1.0 Introduction

Energy availability is fundamental to economic and sustainable development and is intrinsically linked to key global challenges such as poverty, climate change, air pollution, and energy security [1]. The ongoing decline in demand and the gradual shift on the dependence and use of conventional energy sources as a result of its environment consequences have intensified the need to a shift in the use of alternative energy options [2 - 4]. Among these alternatives, solar energy is particularly attractive due to its cleanliness and widespread availability across most regions of the world [5 - 6]. Solar radiation intensity data are essential for a wide range of applications, which include the assessment of agricultural potential, meteorological and evaporation forecasting, architectural design, and the modeling of land, oceanic, and hydrology systems.

Solar collectors harness energy from the sun to generate heat through solar thermal collectors and electricity through photovoltaic systems. Their applications range from residential usage to large-scale industrial operations. A thorough knowledge of the amount and variability of solar radiation at a particular location is critical during the design stages of solar energy systems, as it directly influences cost, performance evaluation, and maintenance requirements. Since solar radiation at the Earth's surface varies with local meteorological conditions, reliable information on solar radiation availability at a specific location is essential for the proper design and selection of solar energy conversion systems [7].

Nigeria is situated in the tropical zone of West Africa and receives high levels of solar radiation due to its geographic location within the inter-tropical region [8 - 9]. This considerable solar energy potential underscore Nigeria's suitability for large scale deployment of photovoltaic systems. This, in turn can stimulate the growth of small and medium scale industries, enhance access to affordable and reliable energy for off-grid consumers and during periods of electricity outage to those connected to the national grid system, and mitigate rural-urban migration by promoting socioeconomic development and improve livelihoods within rural area.

At present, the Nigerian Meteorological Agency, which is mandated with the responsibility for monitoring and measuring climatic parameters across the country, does not routinely measure solar radiation intensities for most locations within Nigeria. In 1992, the Nigerian Building and Road Research Institute (NBRRI) implemented a nationwide solar radiation monitoring programme comprising thirty experimental stations distributed across Nigeria for the acquisition of hourly and daily global solar radiation data using the LN-3000/10 pyranometer solar recorder, the programme lasted for five-year due to persistent equipment malfunctions at several stations, coupled with the unavailability of spare-parts [10 - 11]. The programme was initiated to overcome calibration inconsistencies, and empirical conversion errors inherent in solar radiation data from the Meteorological Station, Oshodi, where measurements were obtained using the Gunn–Bellani radiometers [11].

Consequently, these operational constraints necessitated the development and application of empirical solar radiation models based on alternative meteorological parameters, particularly sunshine duration, to estimate solar radiation for locations lacking reliable direct measurements [12]. The solar radiation datasets acquired through the NBRRI monitoring network, together with those derived from validated empirical models, were subsequently integrated to generate the first solar radiation distribution maps of Nigeria [10 - 11]. Hence, the primary objective of this study is to analyze a comprehensive measured solar radiation data for Nigeria in order to evaluate the feasibility and viability of solar energy availability, as well as its spatial variability across the country, for sustainable alternative energy source.

2.0 Material

Nigeria is situated along the western coast of Africa, extending between latitudes 3°15′N and 13°30′N and longitudes 2°59′E and 15°00′E [13]. The country is bordered by the Republic of Niger to the north, the Republic of Chad and the Republic of Cameroon to the east, the Republic of Benin to the west, and the Bight of Biafra to the south. Nigeria is commonly delineated into Northern and Southern regions. Between these two broad regions lies the Middle Belt, a transitional zone characterized by its arid influence of the Sahara Desert in the north and the coastal influence of the Bight of Biafra in the south.

The average global solar radiation intensity data covering a period of forty-one (41) year (1984 - 2025) were obtained for forty-seven (47) locations from the National Aeronautics and Space Administration (NASA) database. The NASA solar data-set is derived from satellite-based observations, from which surface insolation values are estimated [14]. The selected locations consist of major urban centers across Nigeria, thereby ensuring that the derived solar radiation data are representative and can be reasonably extrapolated to adjacent communities.

3.0 Methodology

3.1 Measurement of Solar Radiation

Solar radiation is measured using two specialized radiometric instruments: a pyrheliometer (actinometer) designed to measure direct beam solar radiation at normal incidence. It employs a collimated tube to restrict its field of view, thereby capturing radiation from the solar disc and a small circumsolar region only [15 -17]. Pyrheliometers are typically mounted on a solar tracker to maintain alignment with the sun throughout the day and a pyranometer (solarimeter), in contrast, measures global solar radiation on a horizontal surface, which consists of both direct and diffuse components [15 - 17]. When fitted with a shading ring or disc to block the direct beam radiation, the instrument can be used to measure diffuse solar radiation exclusively [15, 17].

3.2 Estimation of Solar Radiation

In locations where measured solar radiation data are unavailable, solar radiation data is commonly estimated using empirical correlations derived from other locally measured meteorological variables, such as sunshine duration, temperature, relative humidity, or cloud cover [18 - 20]. Such models, especially sunshine-based models like Angstrom-Prescott and variants continues to be favoured for their balance of accuracy and practicality [21, 22]. To predict the amount of incident global solar radiation on a horizontal surface from measured hours of bright sunshine, the Angström–Page model is commonly employed. The model establishes a linear relationship between the ratio of measured solar radiation to extraterrestrial solar radiation and the ratio of actual sunshine duration to the maximum possible sunshine duration. The Angström–Page model is expressed as [23]

$$\frac{\bar{H}}{\bar{H}_o} = a + b\frac{\bar{n}}{\bar{N}} \qquad (1)$$

Where $\bar{H}$ is the monthly global solar radiation on horizontal surface ($MJm^{-2}day^{-1}$), $\bar{H}_O$ is the monthly extraterrestrial radiation for the study location ($MJm^{-2}day^{-1}$), $\bar{n}$ is the monthly hours of bright sunshine, $\bar{N}$ is the monthly maximum possible hours of bright sunshine and a and b are empirical constants to be determined.

The monthly extraterrestrial radiation for the study location is given as [17]

$$\bar{H}_o = \frac{24\,x3600G_{sc}}{\pi}\left(+0.033cos\frac{360n}{365}\right)x\left(cos\emptyset\,cos\delta\,sin\omega_s + \frac{\pi\omega_s}{180}\,sin\emptyset\,sin\delta\right) \qquad (2)$$

Where G_{sc} is the solar constant given as 1367 W/m^2 [13], n is the day of the year, $\emptyset$ is latitude of study location, δ is the solar declination and ω_s is the sunset hour angle.

The declination (δ) and sunset hour angle (ω_s) can be calculated from the following equations [17]

$$\delta = 23.45 sin\left[\frac{360}{365}(284 + n)\right] \qquad (3)$$

$$\omega_s = cos^{-1}(-tan\phi \; tan\delta) \qquad (4)$$

The monthly maximum possible hours of bright sunshine is given as [17]

$$\bar{N} = \frac{2}{15} cos^{-1}(-tan\phi \; tan\delta) \qquad (5)$$

3.3. NASA Solar Radiation Datasets

The solar radiation datasets developed by the National Aeronautics and Space Administration are widely recognized as a reliable global source of long-term surface meteorological and solar resource information. These datasets are distributed through the NASA Surface Meteorology and Solar Energy (SSE) archive and its successor, the NASA POWER (Prediction Of Worldwide Energy Resources) project. The data are derived from satellite observations integrated with radiative transfer models to estimate surface shortwave irradiance [24]. The database provides multi-decadal records at hourly, daily, and monthly temporal resolutions on a regular latitude – longitude grid [25].

The key parameters that are recorded by NASA include Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), clearness index, and daily insolation, alongside meteorological variables such as air temperature and wind speed. These datasets are extensively applied in solar energy system design, climate studies, agricultural planning, and environmental modeling [26]. Although NASA solar radiation data offer consistent global coverage, their satellite-derived nature necessitates site-specific validation when high-precision ground measurements are required. The monthly average global solar radiation intensity data for the forty-seven (47) study locations accessed from NASA [14] is presented in Table 1.

Table 1: global solar radiation data for the study locations from 1984 - 2025 (kW-hr/m^2/day)

Locations	*Lat. (°N)*	*Long. (°E)*	*Elev. (m)*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Ave*
Abakaliki	6.33	8.12	88.44	5.47	5.49	5.33	5.24	5.10	4.69	4.24	4.08	4.46	4.91	5.32	5.34	4.97
Abeokuta	7.15	3.37	80.92	4.97	4.97	5.08	5.15	5.04	4.56	3.92	3.69	4.17	4.78	5.13	4.93	4.70
Abuja	9.08	7.4	406.97	5.55	5.68	5.90	5.87	5.61	5.11	4.60	4.26	4.94	5.46	5.84	5.49	5.36
Ado-Ekiti	7.62	5.24	379.21	5.11	5.07	5.13	5.16	5.10	4.62	4.16	3.94	4.33	4.83	5.21	5.03	4.81
Akure	7.26	5.21	379.21	5.10	5.06	5.10	5.13	5.07	4.60	4.14	3.93	4.30	4.80	5.21	5.03	4.79
Asaba	6.21	6.7	103.94	4.99	4.90	4.89	4.92	4.81	4.40	4.01	3.93	4.21	4.60	5.01	4.96	4.63
Awka	6.23	7.09	103.94	5.19	5.15	5.10	5.09	4.95	4.55	4.13	4.02	4.34	4.74	5.16	5.13	4.79
Bauchi	10.31	9.83	518.79	5.74	5.96	6.26	6.29	6.09	5.86	5.53	5.23	5.70	5.98	6.03	5.74	5.86
Benin-City	6.34	5.61	93.92	4.93	4.79	4.76	4.81	4.74	4.29	3.76	3.74	4.04	4.51	4.97	4.90	4.52
Bida	9.08	6.01	126.59	5.30	5.50	5.78	5.84	5.67	5.12	4.58	4.26	4.88	5.44	5.70	5.32	5.28
Birinin Kebbi	12.44	4.2	241.96	5.40	5.75	6.08	6.34	6.27	6.12	5.73	5.36	5.83	6.03	5.70	5.47	5.84
Calabar	4.98	8.35	39.48	5.08	5.01	4.57	4.61	4.47	3.87	3.33	3.18	3.60	4.01	4.44	4.94	4.26
Damaturu	11.75	11.97	402.61	5.87	6.20	6.52	6.56	6.31	5.98	5.68	5.42	5.89	6.08	5.99	5.78	6.02
Duste	11.75	9.34	465.94	5.56	5.93	6.26	6.43	6.27	5.88	5.74	5.46	5.95	6.00	5.82	5.60	5.91
Enugu	6.46	7.55	151.33	5.19	5.15	5.10	5.09	4.95	4.55	4.13	4.02	4.34	4.74	5.16	5.13	4.79
Gombe	10.2	11.1	381.6	5.82	6.0	6.3	6.3	6.2	5.8	5.4	5.0	5.5	5.9	6.0	5.80	5.88

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	8	8	2		8	5	5	2	6	4	9	7	8	1		
Gusau	12.17	6.68	529.87	5.44	5.76	6.17	6.43	6.29	6.16	5.83	5.39	5.91	6.02	5.71	5.43	5.88
Ibadan	7.38	3.95	188.89	4.97	4.97	5.08	5.15	5.04	4.56	3.92	3.69	4.17	4.78	5.13	4.93	4.70
Ijebu-Ode	6.83	3.92	90.82	4.93	4.93	5.00	5.05	4.78	4.11	3.92	4.17	4.26	4.72	5.08	4.94	4.66
Ikeja	6.61	3.36	25.49	4.93	4.93	5.00	5.05	4.78	4.11	3.92	4.17	4.26	4.72	5.08	4.94	4.66
Ikom	5.97	8.73	116.85	5.27	5.27	4.98	4.91	4.67	4.21	3.71	3.55	4.07	4.45	4.90	5.08	4.59
Ilorin	8.48	4.55	344.93	5.28	5.37	5.63	5.63	5.45	4.97	4.36	4.09	4.54	5.09	5.48	5.22	5.09
Jalingo	8.9	11.38	251.79	5.87	6.03	6.02	5.84	5.65	5.20	4.65	4.41	4.92	5.54	5.98	5.77	5.49
Jos	9.9	8.86	980.85	5.61	5.78	5.93	5.81	5.47	5.06	4.63	4.31	4.88	5.45	5.95	5.63	5.37
Kaduna	10.52	7.42	623.54	5.70	5.89	6.19	6.32	6.06	5.58	5.08	4.67	5.34	5.79	5.94	5.65	5.68
Kano	12.01	8.6	442.08	5.53	5.90	6.32	6.62	6.50	6.22	5.99	5.67	6.09	6.10	5.82	5.53	6.02
Katsina	12.97	7.63	474.54	5.44	5.73	6.22	6.51	6.35	6.14	5.90	5.47	6.00	6.00	5.68	5.45	5.91
Lafia	8.51	8.52	167.21	5.67	5.75	5.74	5.63	5.43	5.02	4.67	4.37	4.79	5.34	5.82	5.61	5.32
Lokoja	7.81	6.74	167.21	5.16	5.14	5.25	5.27	5.19	4.76	4.39	4.19	4.49	4.94	5.31	5.11	4.93
Maiduguri	11.84	13.16	318.25	5.99	6.35	6.63	6.56	6.31	5.91	5.49	5.22	5.76	6.06	6.04	5.79	6.01
Makurdi	7.74	5.54	373.17	5.10	5.06	5.10	5.13	5.07	4.60	4.14	3.93	4.30	4.80	5.21	5.03	4.79
Mbaise	5.54	7.29	92.75	5.07	5.07	4.92	4.97	4.76	4.31	3.87	3.85	4.17	4.53	4.90	4.95	4.61
Minna	9.58	6.54	149.83	5.30	5.50	5.78	5.84	5.67	5.12	4.58	4.26	4.88	5.44	5.70	5.32	5.28
Nguru	12.88	10.46	345.61	5.72	6.09	6.48	6.69	6.61	6.27	6.07	5.81	6.19	6.19	5.97	5.66	6.14
Onitsha	6.14	6.8	103.94	4.99	4.90	4.89	4.92	4.81	4.40	4.01	3.93	4.21	4.60	5.01	4.96	4.63
Oshogbo	7.79	4.55	337.39	4.93	4.96	5.07	5.07	4.97	4.49	3.85	3.64	4.12	4.67	5.12	4.91	4.65
Owerri	5.47	7.02	62.54	5.07	5.07	4.92	4.97	4.76	4.31	3.87	3.85	4.17	4.53	4.90	4.95	4.61
Port-Harcourt	4.34	7.05	6.8	4.85	4.85	4.48	4.59	4.33	3.65	3.32	3.45	3.67	4.04	4.40	4.76	4.20
Potiskum	11.7	11.09	411.77	5.87	6.20	6.52	6.56	6.31	5.98	5.68	5.42	5.89	6.08	5.99	5.78	6.02
Sokoto	13.01	5.25	276.18	5.58	6.07	6.41	6.58	6.38	6.18	5.95	5.66	6.10	6.10	5.79	5.50	6.02
Umuahia	5.53	7.5	92.75	5.07	5.07	4.92	4.97	4.76	4.31	3.87	3.85	4.17	4.53	4.90	4.95	4.61
Uyo	5.04	7.92	39.48	5.07	5.07	4.92	4.97	4.76	4.31	3.87	3.85	4.17	4.53	4.90	4.95	4.61
Warri	5.55	5.57	9.6	4.86	4.73	4.70	4.82	4.57	3.98	3.46	3.69	3.83	4.35	4.84	4.81	4.38
Yelwa	10.84	4.75	257.74	5.47	5.73	5.92	6.08	6.02	5.62	5.10	4.74	5.23	5.68	5.76	5.44	5.56
Yenegoa	4.93	6.28	17.26	4.85	4.84	4.52	4.67	4.35	3.68	3.39	3.69	3.75	4.18	4.51	4.84	4.27

Yola	9.04	12.5	344.13	5.94	6.19	6.37	6.27	6.00	5.66	5.18	4.88	5.35	5.88	6.07	5.83	5.80
Zaria	11.13	7.73	646.9	5.52	5.82	6.19	6.38	6.21	5.84	5.55	5.17	5.75	5.92	5.77	5.54	5.80
Ave				5.33	5.44	5.54	5.60	5.43	5.00	4.58	4.40	4.81	5.19	5.41	5.27	5.16
Max				5.99	6.35	6.63	6.69	6.61	6.27	6.07	5.81	6.19	6.19	6.07	5.83	6.14
Min				4.85	4.73	4.48	4.59	4.33	3.65	3.32	3.18	3.60	4.01	4.40	4.76	4.20
Max-Min				1.14	1.62	2.15	2.11	2.28	2.61	2.75	2.62	2.59	2.18	1.67	1.07	1.95
(Max-Min/Ave) x 100				21.3	29.8	38.8	37.6	42.0	52.3	60.0	59.6	54.0	42.0	30.9	20.2	37.7

4.0 Discussion

Table 1 reveals that the monthly maximum global solar radiation values vary from 5.81 to 6.69 kWh/m²/day, whereas the monthly minimum values range between 3.19 and 4.85 kWh/m²/day. Therefore, the overall monthly global solar radiation in Nigeria can be considered to fall within the interval of 3.19 to 6.69 kWh/m²/day. This finding is in close agreement with the results report in Ref [27 - 28]. The monthly maximum solar radiation values of 5.81 kWh/m²/day (August) and 6.69 kWh/m²/day (April) were recorded in Nguru, a town in the northern part of Nigeria and border with Niger Republic. In contrast, the monthly minimum global solar radiation values of 3.19 kWh/m²/day (August) and 4.85 kWh/m²/day (January) were measured in Calabar and Port-Harcourt, respectively. These cities are located in the southern region of Nigeria, along the coastal region close to the Bight of Biafra. This spatial variation suggests a greater potential for solar energy harvesting in the northern region compared to the southern region of Nigeria, likely due to differences in climatic and atmospheric conditions.

In a similar vein, the annual average global solar radiation exhibits a minimum value of 4.20 kWh/m²/day in Port-Harcourt and a maximum value of 6.14 kWh/m²/day in Nguru. These findings demonstrate a pronounced latitudinal variation in solar radiation distribution across Nigeria, with the up-northern region possessing significantly higher solar energy potential than the down-southern coastal region. It is further observed that the overall average maximum and minimum monthly global solar radiation values occur in April (5.60 kWh/m²/day) and August (4.40 kWh/m²/day), respectively. This pattern suggests a higher potential for solar energy harvesting in April, which typically represents a transitional period between the dry and rainy seasons and is characterized by relatively clear skies and increased solar insolation. Conversely, the lower average value recorded in August indicates reduced solar energy availability across Nigeria during this period, as the month is generally associated with intense rainfall, increased cloud cover, and higher atmospheric moisture content, all of which contribute to the attenuation of incoming solar radiation which is more noticeable and prominent in the southern region.

Climatically, Nigeria experiences two principal seasons: the dry season and the rainy season [29]. The dry season typically spans from November to April and is dominated by the north-east trade winds originating from the Sahara Desert. These winds are cold, dry, and dust-laden, frequently resulting in hazy atmospheric conditions due to suspended particulates. The rainy season generally extends from May to October, with marked spatial variability in rainfall distribution and intensity across the country.

For the study locations, a cumulative monthly average global solar radiation of 61.99 kWh/m²/day is estimated. The dry and rainy seasons account for 51.92 % and 48.08 %, respectively, of the cumulative monthly average. This distribution indicates the possibility of a greater harvest of more solar radiation during the dry season than the rainy season, hence, reflecting the influence of reduced cloud cover and lower atmospheric moisture content during the dry period.

Furthermore, the least favorable month, August, contributes 7.10 % to the total monthly average solar radiation, whereas the most favorable month, April, accounts for 9.03 %. This contrast further highlights the pronounced seasonal variability in solar resource availability, with peak solar insolation occurring during the late dry-season transition period and the lowest values recorded during the height of the rainy season. Table 1 further reveal that July exhibits the greatest intra-monthly variability in solar radiation, with a fluctuation range corresponding to 60.0 % of its monthly average value. Conversely, December demonstrates the least variability, with a range amounting to only 20.2 % of its respective monthly average. This pronounced variability in July may be attributed to heightened atmospheric instability during the peak of the rainy season, characterized by persistent cloud cover, convective activity, and frequent precipitation events that significantly modulate surface solar irradiance. In contrast, the relatively low variability observed in December reflects the stable synoptic conditions of the dry season, marked by clearer skies and reduced atmospheric attenuation, which contribute to more uniform solar radiation levels.

Following the work of Ref. [30] as cited in Ref. [31], the global solar radiation zone derived from the data in Table 1 are presented as follows in Table 2.

Table 2 annual monthly average global solar radiation zone

Zones	Annual average of global solar radiation (kWh/m²/day)	Locations
Zone I	5.50 - 6.15	Bauchi, Birinin kebbi, Damaturu, Duste, Gombe, Gusau, Kaduna, Kano, Katsina, Maidugri, Nguru, Potiskum, Sokoto, Yelwa, Yola, Zaria
Zone II	4.85 - 5.50	Abakaliki, Abuja, Bida, Ilorin, Jalingo, Jos, Lafia, Lokoja, Minna
Zone III	4.20 - 4.85	Abeokuta, Ado-Ekiti, Akure, Asaba, Awka, Benin-City, Calabar, Enugu, Ibadan, Ijebu-Ode, Ikeja, Ikom, Makurdi, Mbaise, Onitsha, Oshogbo, Owerri, Port-Harcourt, Umuahi, Uyo, Yanegoa

Table 2 presents the distribution of annual average global solar radiation intensity across Nigeria, with each zone characterized by a distinct level of solar radiation intensity. Zone I comprises locations situated in the far northern region of Nigeria, within the latitudinal belt of 9.04°N to 13.01°N. This zone corresponds largely to the semi-arid and arid climatic belts of the country, which are characterized by low annual cloud cover, high atmospheric transmissivity, and prolonged dry seasons as a result of the influence of the Sahara Desert. These meteorological conditions contribute to relatively high levels of incoming solar radiation throughout the year. The annual average global solar radiation intensity within this zone ranges between 5.50 and 6.15 kWh/m²/day, reflecting a consistently high solar resource base. Such magnitudes of solar irradiance underscore the significant potential of this region for solar energy exploitation, particularly for grid-connected photovoltaic systems, concentrated solar power technologies, and off-grid rural electrification schemes.

Zone II comprises locations that have average annual global solar radiation values ranging from 4.85 to 5.50 kWh/m²/day, situated within the latitudinal belt of 6.33°N to 9.9°N. Based purely on latitudinal positioning, it is expect that Abakaliki (6.33°N) should be classified within Zone III. However, its value of annual global solar radiation indicate that Abakaliki falls within Zone II, suggesting that factors other than latitude such as cloud cover, atmospheric moisture content, and other climatic influences play a significant role in determining the spatial distribution of solar radiation across a given location.

Zone III consist of locations with average annual global solar radiation values ranging from 4.20 to 4.85 kWh/m²/day. This zone is characterized by relatively high annual rainfall and persistent cloudiness, which enhance atmospheric attenuation of incoming solar radiation and consequently reduce the amount of solar energy reaching the Earth's surface.

Global solar radiation consists of beam and diffuse components, both of which are effectively utilized by flat-plate solar collectors [17]. Given that flat-plate devices can harness both components, solar collectors such as photovoltaic (PV) modules, solar water heaters, and solar food dryers demonstrate strong technical potential for solar energy exploitation in Nigeria, particularly in the northern region where solar resource availability is comparatively higher. Photovoltaic systems, in particular, offer viable applications for rural electrification in off-grid communities, supporting household electricity supply, water pumping, and irrigation. In grid-connected areas, PV installations can also serve as supplementary or backup power sources during periods of supply interruption, thereby enhancing energy reliability and resilience. However, despite their technical and environmental advantages, solar photovoltaic (PV) systems are associated with relatively high initial capital costs, which constitute a significant barrier to adoption among low-income households in Nigeria [32].

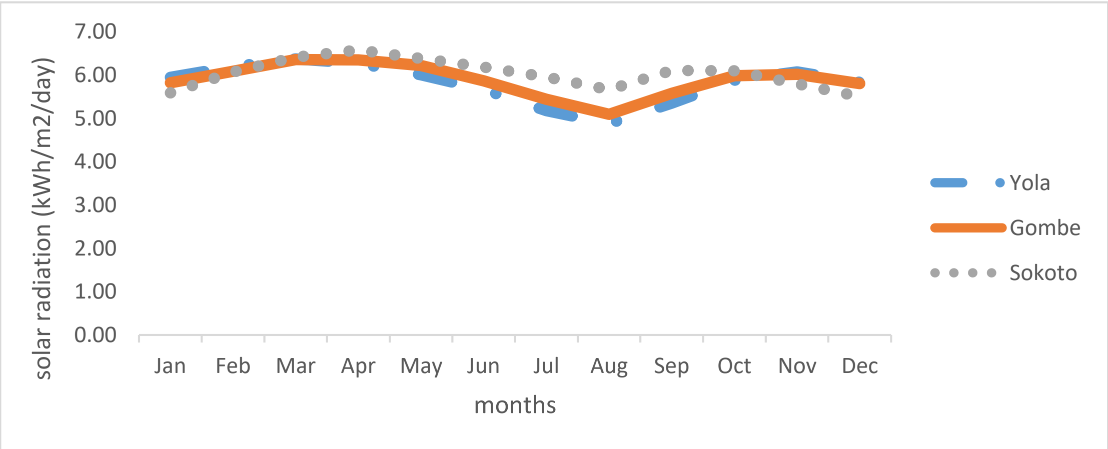

Figure 1 monthly global solar radiation of three locations in Zone I

Figure 1 illustrates the monthly global solar radiation profiles for three representative cities located within Zone I. The results indicate that inter-city variability in solar radiation is relatively minimal, notwithstanding the differences in latitude among the selected locations. This limited spatial variation suggests a high degree of homogeneity in solar resource distribution across the zone. Furthermore, the observed consistency implies that other locations situated within the same latitudinal belt are likely to exhibit comparable solar radiation characteristics. Such spatial uniformity enhances the reliability of regional solar resource assessments and supports the generalization of solar energy planning and system design parameters across Zone I.

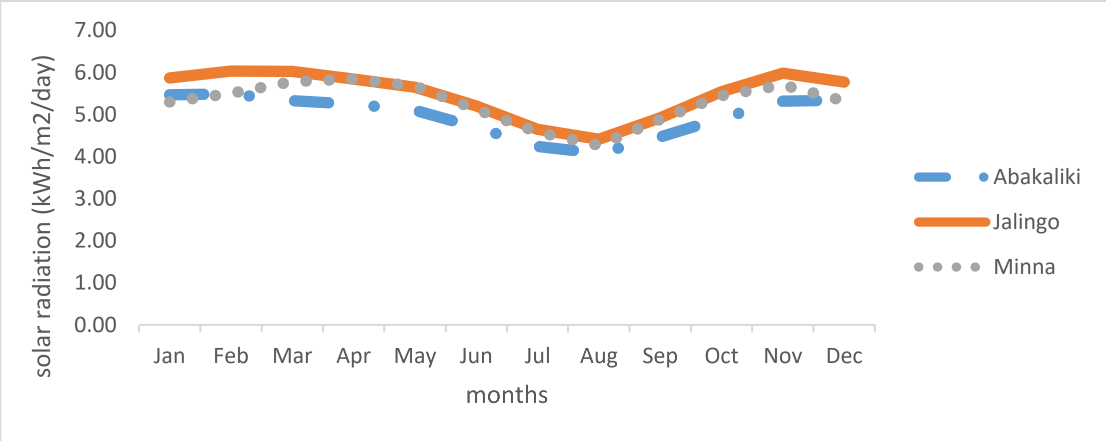

Figure 2 monthly average global solar radiation of three locations in Zone II

Figure 2 illustrates the monthly average global solar radiation for selected locations within Zone II. This zone occupies an intermediate latitudinal position in Nigeria, lying approximately equidistant from the arid influence of the Sahara Desert to the north and the humid coastal influence of the Bight of Biafra to the south. As such, it represents a transitional climatic belt characterized by moderate atmospheric moisture content and seasonal variability.
The results indicate that the three locations exhibit comparable levels of monthly average global solar radiation. This similarity persists despite their differences in geographic latitude, with Abakaliki situated at approximately 6.33°N, while Jalingo and Minna are located at about 8.90°N and 9.58°N, respectively. The relatively small variation in solar radiation among these cities suggests that, within this transitional climatic zone, latitudinal differences exert a limited influence on the magnitude of global solar radiation. Instead, regional atmospheric dynamics and seasonal cloud patterns appear to play a more dominant role in shaping the spatial distribution of solar resources. Consequently, other locations within Zone II are likely to demonstrate similar solar radiation characteristics.

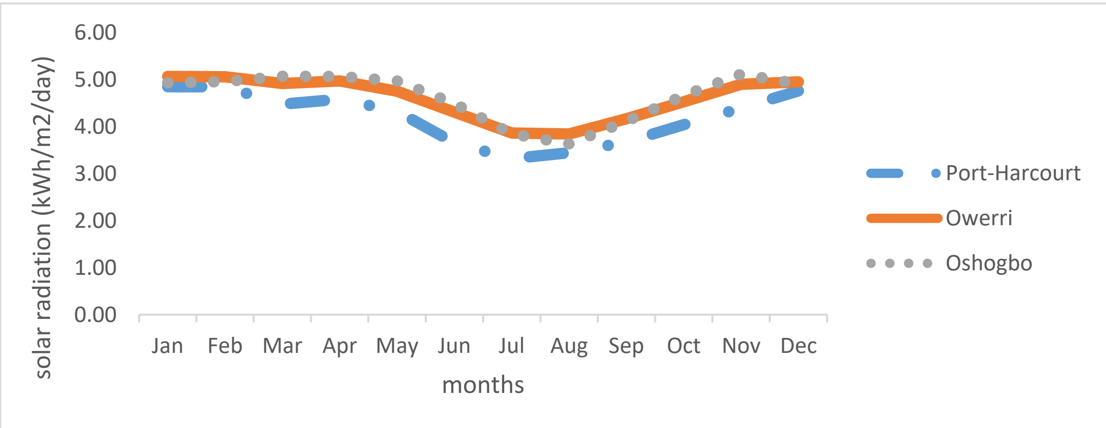

Figure 3 monthly average global solar radiation of three locations in Zone III

Figure 3 illustrates the monthly mean global solar radiation for selected locations within Zone III, situated between latitudes 4.34°N and 7.74°N. This zone largely corresponds to the humid tropical belt of the country, which is characterized by prolonged and intense rainfall during the wet season, high relative humidity, and persistent cloud cover resulting from strong coastal influence of the Bight of Biafra. Despite these prevailing climatic conditions, the monthly average global solar radiation within the zone ranges from 4.2 to 4.85 kWh/m²/day. Although these values are comparatively lower than those observed in Zones I and II, they nevertheless indicate a moderate and viable solar energy resource. The reduction in solar radiation intensity is primarily attributable to increased cloud attenuation, elevated atmospheric moisture content, and frequent convective activity, particularly during the peak rainy months. The relatively narrow radiation range across the selected locations further suggests a degree of spatial uniformity within this humid latitudinal belt. Consequently, other areas situated within the 4.34°N – 7.74°N corridor are likely to exhibit comparable solar radiation characteristics.

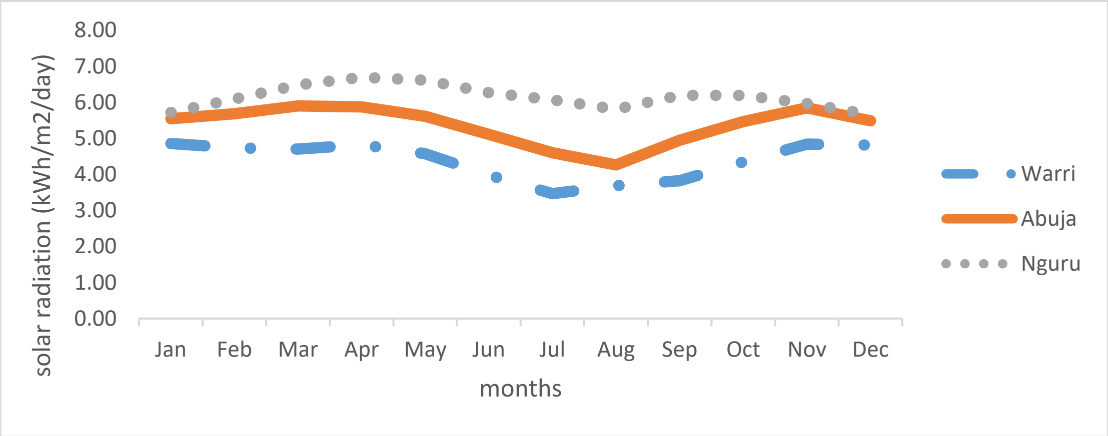

Figure 4 monthly average global solar radiation for different Zones

A comparative analysis of the monthly mean global solar radiation across the three zones of Nigeria is presented in Figure 4. The radiation profiles of Abuja (Zone II) and Nguru (Zone I) exhibit closely similar seasonal trends, characterized by analogous temporal patterns throughout the year. However, a noticeable difference exists in the absolute magnitude of solar radiation intensity, with Nguru generally recording higher values, consistent with its location in the more arid northern belt. Interestingly, both locations converge to nearly identical radiation levels during the months of November, December, and January, suggesting a period of reduced latitudinal contrast in atmospheric conditions and cloud dynamics. In contrast, the radiation profile of Warri (Zone III) demonstrates greater intra-annual fluctuation. This variability reflects the stronger coastal influence and heightened cloud formation associated with the humid southern region, particularly during the peak rainy season. Furthermore, it is observed that all three locations record their minimum monthly average global solar radiation in August, as evidenced by the pronounced trough in their respective curves. This consistent depression across the zones indicates that August represents the least favorable month for solar energy harvesting in Nigeria, likely due to intensified cloud cover, high atmospheric moisture content, and reduced atmospheric transmissivity during the peak of the rainy season. Such findings are critical for optimizing solar system sizing, storage design, and energy yield projections on a national scale.

5.0 Conclusion

This study provides a comprehensive long-term assessment of solar radiation distribution across Nigeria and establishes a robust basis for informed solar energy planning. The consistency of solar availability throughout the year, despite identifiable seasonal fluctuations, indicates strong potential for reliable solar energy exploitation across diverse climatic zones. The spatial differentiation observed across the country further emphasizes the need for region-specific deployment strategies to optimize system performance and investment returns.The findings presented supports the strategic prioritization of solar energy within Nigeria's energy transition framework. Harnessing this abundant resource offers a practical pathway to strengthening energy resilience, reducing dependence on conventional fossil-based energy generation, and advancing sustainable socio-economic development.

References

[1] Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the IPCC Sixth Assessment Report.
[2] International Energy Agency (2023): World Energy Outlook 2023. www.iea.org
[3] IRENA (2024): Renewable Power Generation Costs in 2023, International Renewable Energy Agency, Abu Dhabi. ISBN: 978-92-9260-621-3
[4] Ogueke, N.V., Njoku, M.C., Anyanwu, E.E. (2009) Design, Construction and Testing of a Cylindrical Solar Water Heater. International Journal of Energy for a Clean Environment, 10(1-4), 57-72
[5] Njoku, M.C., Ofong, I., Ogueke, N.V. and Anyanwu, E.E. (2018) Characterization of Sky Conditions at Benin City and Owerri in Nigeria. J.Fundam Renewable Energy App., 8-5, DOI: 10.4172/2090-4541.1000270
[6] Global Solar Atlas World Bank (WB), International Finance Corporation (IFC), Energy Sector Management Assistance Program (ESMAP), Solargis. https://data360.worldbank.org/en/dataset/WB_SOLAR_ATLAS

[7] Ministry of Power (2015) National Renewable Energy and Energy Efficiency Policy (NREEP). Federal Republic of Nigeria, 1-103
[8] Energy Commission of Nigeria (2003) National Energy Policy. Federal Republic of Nigeria, 1-89
[9] National Council on Power (2016) Sustainable Energy for all Agenda (SE4ALL-AA), First Edition, 1-102.
[10] Ojosu J.O. (1988) Solar Radiation Distribution Maps of Nigeria. NBRRI Report No 11. Nigerian Building and Road Research Institute.
[11] Ojosu J.O. (1990) The Iso - Radiation Map of Nigeria. Solar and Wind Technology, 7(5), 563-575
[12] Ojoso J.O. (1990) Development of Solar Radiation Models for Nigeria. NBRRI Report No 8, Nigerian Building and Road Research Institute.
[13] Federal Department of Forestry, Federal Ministry of Environment (2019) National Forest Reference Emission Level (FREL) for the Federal Republic of Nigeria. Pp. 8
[14] National Aeronautics and Space Administration (NASA). http://power.larc.nasa.gov/data-access-viewer Accessed Febuary 20, 2025
[15] World Meteorological Organization (2008). Guide to Meteorological Instruments and Methods of Observation WMO No 8. Seventh Edition, ISBN: 978-92-63100085.3edc Geneva.
[16] International Organization for Standardization (2018). ISO 9060: Solar Energy — Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiation. Edition 2, ISO 9060-2018, Geneva. .
[17] Duffie J.A. and Beckman W.A. (2013) Solar Engineering of Thermal Processes. Fourth Edition, John Wiley & Son Inc. Hoboken, New Jersey.
[18] Gurel, A.E., Agbulut, U., Bakir, H., Ergun, A. and Yildiz, G. (2023) A State of Art Review on Estimation of Solar Radiation with Various Models. Heliyon 9(2023) e13167, https://doi.org/10/10.1016/j.heliyon.2023.e13167
[19] Vernet, A. and Fabregat, A. (2023) Evaluation of Empirical Daily Solar Radiation Models for the Northeast Coast of the Iberian Peninsula. Energies 2023, 16, 2560. https://doi.org/10.3390/en16062560
[20] Prieto, J. and Garcia, D. (2022) Global Solar Radiation Models: A critical Review from the Point of View of Homogeneity and Case Study. Renewable and Sustainable Energy Reviews 155(2022) 111856 https://doi.org/10.1016/j.rser.2021.111856
[21] Ekici, C. (2025) Solar Radiation Estimation using AI-Driven Empirical Model: Calibration and Evaluation. Case Studies in Thermal Engineering 75 (2025) 107080. https://doi.org/10.1016/j.csite.2025.107080
[22] Besharat, F., Dehghan, A.A. and Faghih, A.R. (2013) Empirical Models for Estimating Global Solar Radiation: A Review and Case Study. Renewable and Sustainable Energy Review 21(2013), 798-821
[23] Igbal, M. (1983): An introduction to solar radiation. Academy Press. New York.
[24] Stackhouse, P., Westberg, D., Hoell, J., Chandler, W., and Taiping Zhang (2018). NASA Surface Meteorology and Solar Energy (SSE) Release 6.0 Methodology. NASA Langley Research Center.
[25] NASA (2023). Prediction Of Worldwide Energy Resources (POWER) Data Access Viewer. National Aeronautics and Space Administration. https:data.nasa.gov
[26] White, J.W., Hoogenboom, G., Stackhouse, P.W., & Hoell, J.M. (2008). Evaluation of NASA Satellite- and Assimilation Model–Derived Long-Term Daily Temperature Data Over the Continental US. Agricultural and Forest Meteorology, 148(2008), 1574 – 1584. doi:10.1016/j.agrformet.2008.05.017
[27] Sambo, A.S. (2009) Strategic Developments in Renewable Energy in Nigeria. International Association for Energy Economics, Third Quarter 2009, 15-19
[28] Energy Commission of Nigeria and United Nation Development Programme (2005) Renewable Energy Master Plan. Final Report, 1-227.
[29] Njoku, M.C., Anyanwu, E.E., Azodoh, K.A., Anyanwu, A.U., Madumere, O.J., Micheal, A.O., and Onugha, C.G. (2022) Assessment of Wind Energy Potential in Nigeria. International Journal of Research Publication and Reviews, 3(11), 1620-1627
[30] Huld, T., Suri, M., Dunlop, E., Albuisson, M., and Wald, L. (2005) Integration of Helioclim-1 Database into PV-GIS to Estimate Solar Electricity Potential in Africa. Proceedings, 20th European Photovoltaic Solar Energy Conference, Jun 2005, Barcelone, Spain. Hal-00091923
[31] Ohunakin, O.S., Adaramola, M.S., Oyewola, O.M. and Fagbenle, R.O. (2014) Solar Energy Applications and Development in Nigeria: Drivers and Barriers. Renewable and Sustainable Energy Reviews 32, 294-301.
[32] IRENA (2023) Renewable Energy Roadmap Nigeria. International Renewable Energy Agency. Abu Dhabi. ISBN 978-92-9260-477-61-126.