ANALYSIS OF SOLAR ENERGY POTENTIALS IN KATSINA AND SOKOTO STATES, NIGERIA

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ABSTRACT

For many years, Nigeria has been facing energy crisis that is hampering her economic development. Energy is one of the key fundamentals for economic development and it is also fundamental to all human activities in this era. In this study, renewable energy potentials in Sokoto and Katsina states were analyzed, respectively. Data covering a period of ten years (2007 -2017) were obtained from the Nigerian Meteorological Agency (NIMET), Abuja, for monthly average daily solar radiation, maximum and minimum temperatures for the two states under investigations. The data were subjected to statistical analysis such as normality test, to examine whether the data is normally distributed using standardized coefficient of skewness, and kurtosis using a 250Watts by 1.68m^2 solar panel; the results show that the solar radiations are negatively skewed by a value of -0.6 and -0.43, which makes the two state more reliable during the dry season of the year. The two states have a kurtosis of -1.17 and -1.38 indicating that the bell shape is slightly flatten than normal distribution shape. A linear regression model was also developed to predict the trends in solar radiation for the study area. The results show that Katsina state has a higher reliability (0.86) for solar energy potentials than Sokoto state (0.72).

Keywords:*Energy, Solar Radiation, Linear Regression*

1. Introduction

Energy is one of the key fundamentals for economic development and it is important to all human activities in this era. Nigeria is endowed with vast oil and gas reserves and an abundance of renewable energy potentials [1]. Yet, the country is suffering an energy crisis, which has a major impact on its ability to reduce poverty and achieve the sustainable development goals (SDGs) [2]. Over the last decades, effort has been made to harness renewable energy resources in meeting the global energy demand and to generate energy that is environmentally friendly across the world. In Nigeria today, the main electricity sources are from thermal and hydro power stations. Renewable energy technology is a promising solution to the energy crisis in Nigeria [3]. Adopting the use of renewable energy sources will lead Nigeria to achieve stable energy supply and energy efficiency. Climate change, which is caused as a result of carbon emissions and environmental pollution, is drawing world attention and forcing governments to formulate policies that will make their nations adapt the use of renewable energy sources to cut environmental pollution to the barest minimum because global warming has become a major issue and problem of the world today [4].

The problem of electricity shortage in Nigeria can surely be reduced if the available solar energy resource in the country is properly harnessed for power generation. Nigeria possesses abundant untapped solar energy resources that could meet both the current limited supply and inaccessibility of power in remote villages. Previous investigations show that the northern part of the country has substantial solar energy resources [5]. This study therefore assessed the potentials of solar energy resources in Sokoto and Katsina states to ascertain their viability against specified standards in the literatures. Katsina state is located on latitude 12.5139ºN Longitude 7.6119ºE, while Sokoto state is located on latitude 12.937ºN and longitude 5.25ºE. The two states are located in savannah bio-climatic type with alternating wet and dry season during the years. The northwest region of Nigeria is characterized by strong sunshine especially during the dry season and relatively high temperature. Rainfall is less than 1000mm per annum and occurs in only five months in the year between May and October and therefore, the remaining months have high solar radiation incident [6]. The daily sunshine duration is 8 hours on the average. Air temperatures are constantly high with high evaporation. This work attempted: (i) to analyze, using relevant statistical tools, already established solar intensity data from relevant agencies for the two states under considerations and (ii) interpret the analyzed result for its economic viability.

2. Materials and method

2.1 Solar Irradiation Data

The Nigerian annual average solar radiation varies from approximately 12.6 MJ/m^2/day (3.5 kWh/m^2/day) in the coastal latitudes to approximately 25.2 MJ/m^2/day (7.0 kWh/m^2/day) in the extreme north [7]. The northern region of Nigeria has the greatest potential for electricity generation from the solar radiation [7]. The solar data used for this study were collected from Nigerian Meteorological Agency (NIMET) and covered a period of ten years (2007-2017). The data shows the monthly average daily solar radiation, maximum and minimum temperatures of the two state under consideration.

Solar radiation dataset is the key parameter for the determination of solar PV output at all time and location. Several solar radiation data sources exist across the globe but none of them is perfect. The most common types of solar radiation data source include ground measurements and satellite-based measurement or calculations.

2.2 Clearness Index

The clearness index assessment was carried out, which is a measure of the clearness of the atmosphere. It is the fraction of the solar radiation that is transmitted through the atmosphere to strike the surface of the Earth. It is a dimensionless number between 0 and 1, defined as the surface radiation divided by the extra-terrestrial radiation, as shown in equation 1.

$$K_t = \frac{I_{average}}{I_{extra}} \qquad (1)$$

Where $I_{average}$ is the average solar radiation and I_{extra} is the extraterrestrial radiation

2.3 Solar Energy Resource Reliability

The percentage of time in days in a given period or season in which available daily global radiation reaches or exceeds a reference threshold radiation value is a measure of its reliability. The reliability (δ_R) was quantified through equation 2.

$$\delta_R = \frac{n100}{N} \qquad (2)$$

Where n = the total number of days in which daily global radiation reaches or exceeds the reference threshold value and N is the total number of days in the month/season respectively. In this study, the threshold value has been taken as the minimum daily power requirement for moderate temperature to high temperature activities. For ease of counting due to voluminous data involved, the daily global radiation dataset was converted into two dummies (1- for any value equal or above the threshold, 0 - for any value below the threshold). Threshold values used were 5.4kWh/m^2 /day and 6.8kWh/m^2 /day for moderate and high temperature activities respectively.

2.4 Solar Panel Chosen for Estimating the Electricity Generation

Crystalline silicon type solar panel with the following specifications was chosen to estimate the electricity generation potentials: Nominal power: 0.26 kW, Peak power: 250 W, PV efficiency: 15%, and Panel Area: 1.68 m^2.

2.5 Solar Photovoltaic Electricity Generation

Global formulation of electricity generation of Photovoltaic system estimation is expressed in the equation 3 as:

$$E = A \times r \times H \times PR \qquad (3)$$

Where,
E = Energy Output (W, kW, kWh) depending on the formulation,
A = Total solar panel Area (m^2),
r = Solar panel yield (%),
H = Annual average solar radiation on tilted panels (shadings not included) and

PR = Performance ratio, coefficient for losses ranges (0.5-0.9 with default 0.75). Although with the amount of solar radiation of the two states, several tools are design globally to compute the output of PV system in a very user-friendly format.

2.6 Method of Data Analysis

Materials for the research include record of daily sunshine and temperature of the two states for ten years, (2007 -2017). The collected data were subjected to some statistical examinations such as normality test to examine whether the data is normally distributed using the standardized coefficient of Skewness (Z1) and Kurtosis (Z2) in equations 4 and 5 respectively.

$$Z_1 = \left[\frac{\left\{ \frac{\left[\sum_{I=1}^{N}(x_1-\bar{x})^3\right]/N}{\left[\sum_{I=1}^{N}(x_1-\bar{x})^2/N\right]^{3/2}} \right\}}{(6/N)^{1/2}} \right] \qquad (4)$$

Kurtosis

$$Z_2 = \left[\frac{\frac{\sum_{I=1}^{N}(x_1-\bar{x})^4}{N} \Big/ \sum_{I=1}^{N}(x_1-\bar{x})^2 N}{\sqrt{24/(N-3)}} \right] \qquad (5)$$

Linear regression technique was also used to test for trends in the solar radiation, in order to determine whether there are any monotonic increases or decreases in the average values between the beginning and the end of the study period. The computed means stand as long term means for the annual totals (for the entire period/state). The decadal mean were compared with long term mean and their significance tested using crammer's test.

$$t_k = \frac{\left[n(N-2)/N - n(1+t_k^2)\right]}{2t_k} \qquad (6)$$

3.0 Results and discussion

3.1 Results

The data collected from NIMET for the solar radiation of the two study states includes the daily solar radiation incident in the states, the temperature on the two states. The data are presented graphically in figures 2 – 3. Figure 1(a – c) shows from the data collected the yearly solar radiation incident on Katsina over the study period (2007 - 2017), while figures 1(b) and 1(c), show the average and total solar radiation in Katsina state. From the three graphs it was observed that the radiation incident on the twelve month of the year have a bell shape, i.e. during the raining months the average solar radiation is far lower than during the dry seasons. But over the ten (10) years of the study, the radiation incident had the same pattern.

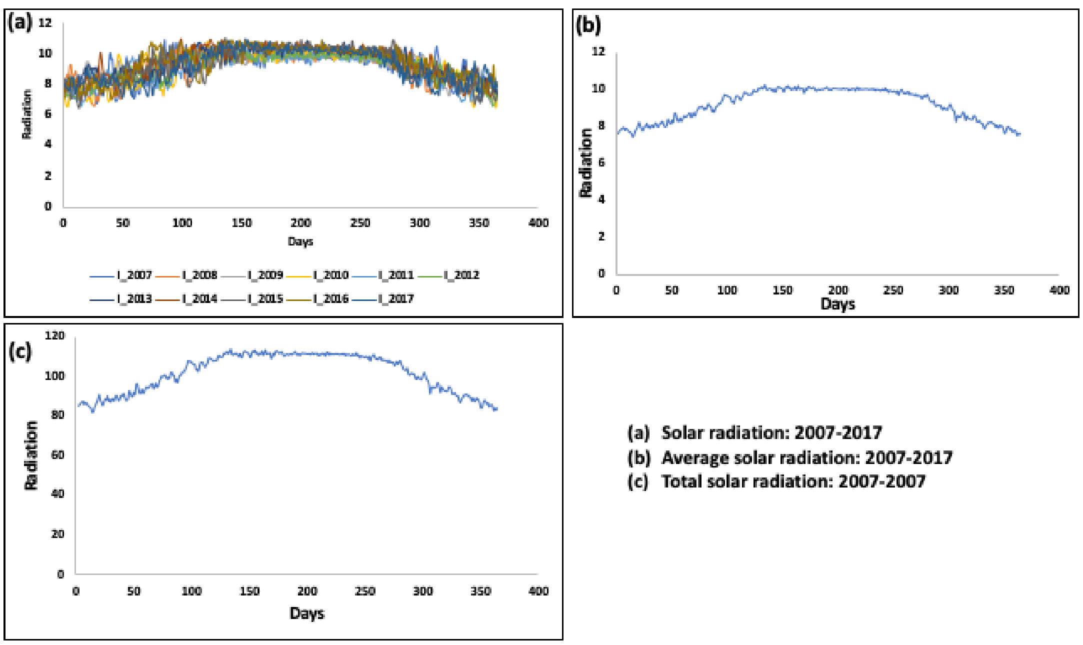

Figure 1: Solar radiation over Katsina State

From figure 1, Katsina has a maximum, minimum, average and total solar radiation of 11.03, 6.43, 9.22 and 37,033.46 MJm^{-2} day^{-1} respectively. The highest solar radiation during the dry season for Katsina state is 9.95. The radiation during the months of dry season more stable from the data as compare to the raining season.

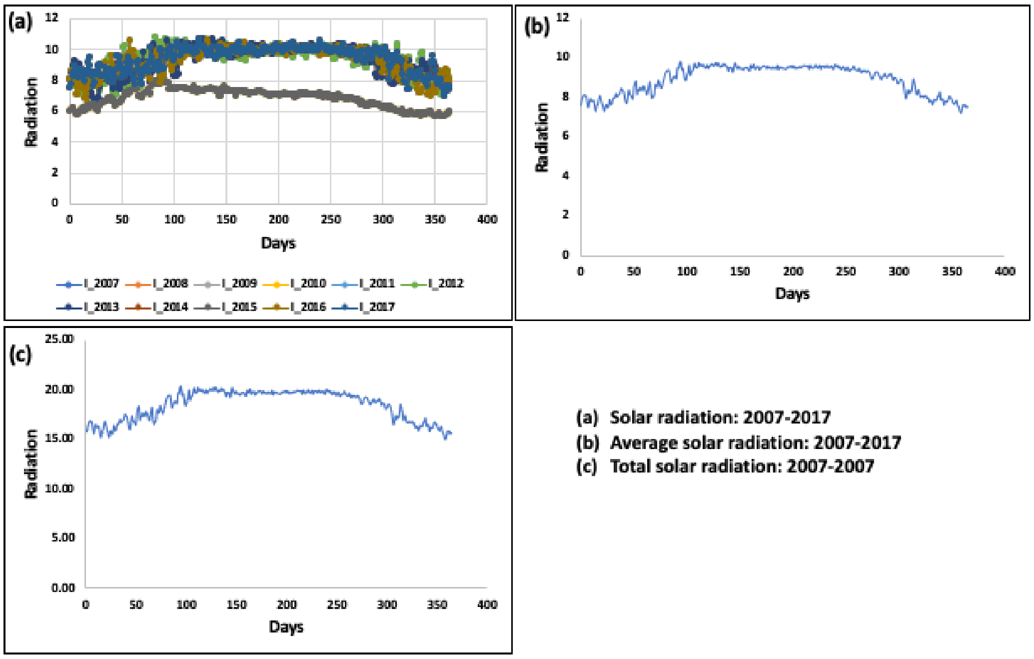

Figure 2: Solar radiation over Sokoto State

From figure 2, Sokoto state has a maximum, minimum, average and total solar radiation of 10.83, 5.46, 8.86 and 35,556.00 respectively. The highest solar radiation during the dry season for Sokoto state is 9.43. the radiation incident of Sokoto for 2015 were very low from data collected with the lowest yearly average solar radiation of 5.46, during this year a minimum temperature of 10.99°C was recorded.

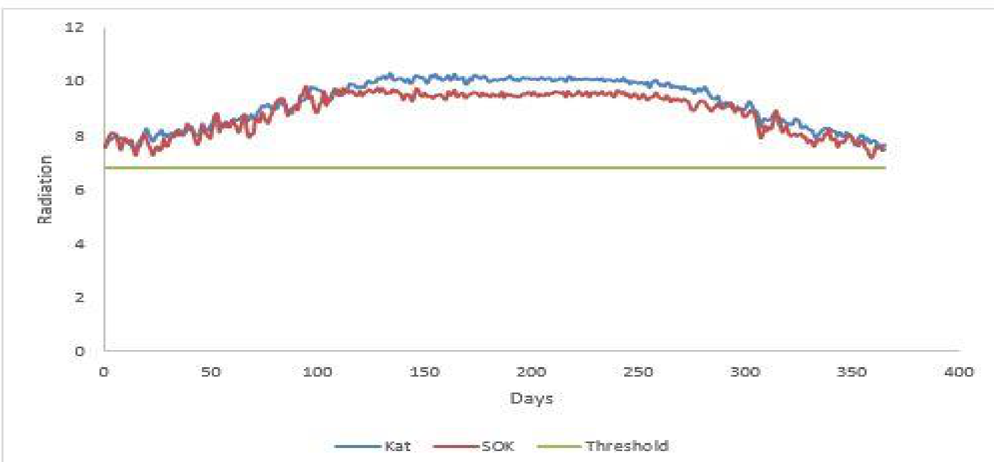

Figure 3: Average Solar Radiation for Katsina and Sokoto State from 2007-2017.

A comparison of the solar radiation incidence in the two states is shown in figure 3, during the raining season the two states are fairly the same. At the end of the raining season, it dropped to its lowest and starts raising from January to May on the yearly basis. During the dry season the radiation incident for the two states have an almost zero slope. But the season for Katsina average over the study period is higher than that of Sokoto by almost 4% (3.9%).

3.2 Results of the Clearness Index

The clearness index is a measure of the clearness of the atmosphere. Figure 4 shows the clearness index for the comparison of the two states.

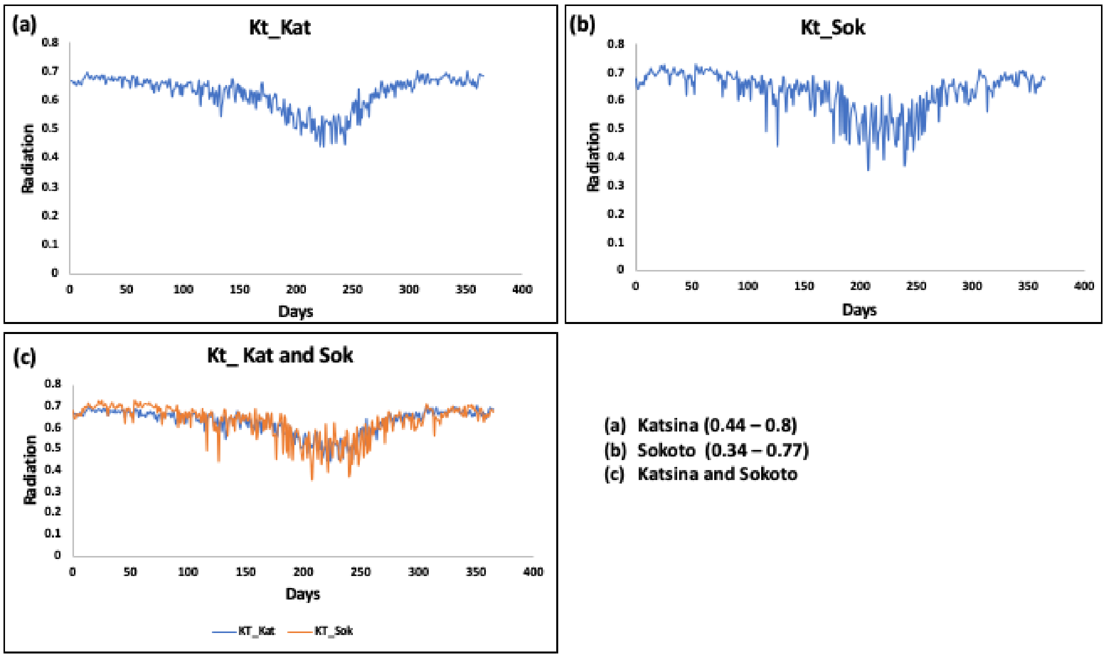

Figure 4: Clearness index

Figure 4 presents the plots of the daily variations of the clearness index (K_t) for both states and this serve as a hints for discussing the sky conditions of Katsina and Sokoto states in the process of transmitting and scattering of incoming solar radiation. Low clearness means low global radiation which usually attributes to a cloudy sky with high portion of diffuse components. Large values of clearness index means high global radiation, which is dominated by the direct component. It is also seen that figure 4 shows a dip patterns of the clearness index during the dry season indicting a high diffuse solar radiation for the two states. The clearness index (K_t) value ranges between 0.34 – 0.77 (Sokoto) and 0.44 – 0.8 (Katsina). The lowest values of the K_t concedes with the period of high solar radiation incident in the two states.

3.3 Electricity Solar Power Potentials for Katsina and Sokoto States

Solar energy can be converted into electricity for use via PV panels' conversion, a 250W PV panel were used, as earlier stated in section 2.4, to simulate the collected data for the two states. As expected from figure 5, the power output pattern is the same as the radiation pattern and also opposite the clearness index.

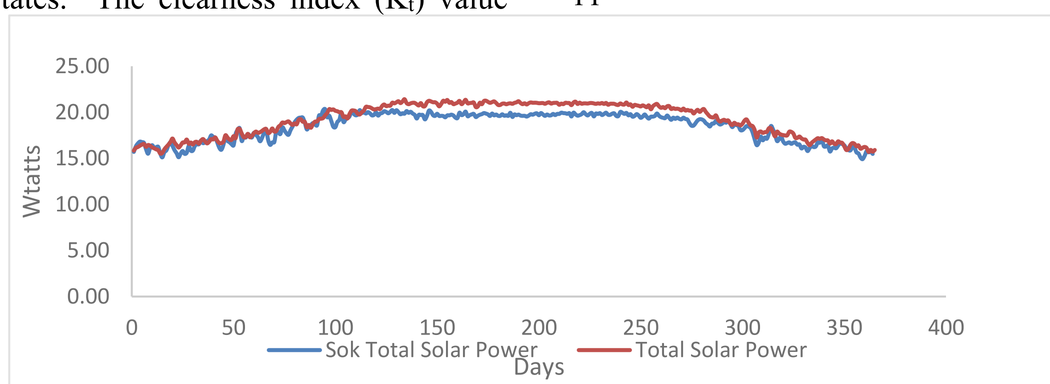

Figure 5: Comparison of the Power estimated for Sokoto and Katsina states.

The minimum, maximum and average power estimates for the Sokoto and Katsina states are 14.91, 20.33, 18.41 and 15.52, 21.42 19.16 respectively. The PV used for this simulations have an area of 1.68 m^2. And according to total surface area of the Sokoto state and Katsina state 25,973 km^2 (2.5973×10^{10}) and 24,192 Km^2 (2.42×10^{10}). The implies that a 1.03893×10^{14} W and 1.00824×10^{14} W electricity are possible from the two states considering the total area of the two states and annual total radiation. However, given that it is not feasible to use the entire landmass for solar PV installation, at least half of these projections can arguably be achieved.

3.4 Results of Statistical Analysis

Statistical analyses were conducted in other to study the behaviour pattern of the collected data. The nature and behaviour of the data can reveal the potential and reliability of the collected data. The results of the descriptive statistics conducted on the collected solar radiation data are presented in table 1.

Table 1: Results of the descriptive statistics

	Katsina	Sokoto
Mean	8.86	9.22
Standard Error	0.04	0.05
Median	9.23	9.54
Mode	9.34	10.11
Standard Deviation	0.74	0.87
Sample Variance	0.55	0.75
Kurtosis	-1.17	-1.38
Skewness	-0.60	-0.43
Range	2.61	2.84
Minimum	6.43	5.46
Maximum	11.03	10.83
Sum	37,033.46	35,556.00
Count	3650	3650

The data collected were for ten (10) years of the two states. The standard error for Katsina and Sokoto are 4% and 5% respectively. This error is within an acceptable region for a reliable data. The most important statistical variable in table 1 are skewness and Kurtosis. The skewness of a data is a measure of the peak values of the data relative to normal distribution curve, while, kurtosis reveals the relative shape of the data to that of a normal distribution. Solar radiation data of Katsina state and Sokoto state are negatively skewed by a value of -0.6 and -0.43, which mean the distribution tails are slightly shifted (or skewed) towards the right hand side as shown in figure 6. i.e the solar radiation of the two states are more reliable during the dry season of the year or the solar radiation fluctuates during the early stages of the graph (i.e. during the raining season). The two states have a kurtosis of -1.17 and -1.38, which means that the bell shapes are slightly flatten than the normal distribution shape (plantykurtic in nature).

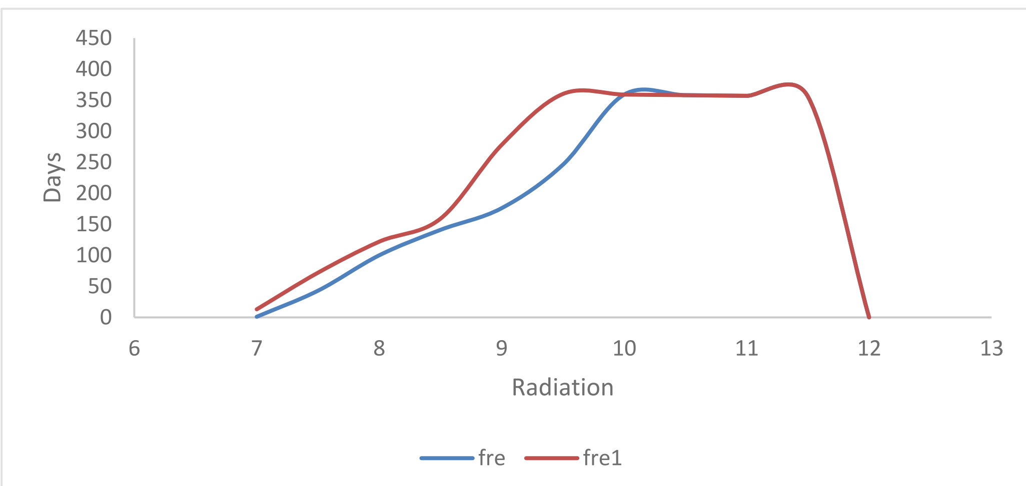

Figure 6: Frequency distribution of the Solar Radiation for the two states.

3.5 Reliability of Results

Reliability is the degree by which the result of a measurement or calculation can be depended on to be accurate. Therefore, the frequency of solar radiation of the study states been above the recommended threshold capable of generating electricity were estimated and the reliability calculated are shown in table 2.

Table 2: Reliability of electricity generation for the Sokoto and Katsina states

Year	Katsina State	Sokoto state
2008	1	0.7
2009	1	1
2010	0.8	0.7
2011	1.0	0.9
2012	0.9	0.7
2013	1	0.8
2014	0.7	0.6
2015	0.8	0.3
2016	0.7	0.6
2017	0.7	0.7
Average Reliability	0.86	0.72

From table 2, Katsina state has a higher reliability for generating electricity solar resource than Sokoto state. This is because from the data collected Katsina state has more numbers of days with solar radiation is more than the recommended threshold. Also, the average values of solar radiation and clearness index agrees with the results in table 2

4 Conclusions

This research work is aimed at analyzing solar energy potentials in Sokoto and Katsina states. Therefore, solar radiation data of the two states were collected for ten (10) years for analysis. Two analysis were carried out i.e. electricity potentials of the collected data and descriptive statistical analysis. The average solar radiation from the two states are more than the global threshold for radiations of 6.8 kWh/m^2 /day for high temperature regions. The results of the analysis conducted shows that energy from solar radiation are very reliable for electricity generation during the off-raining season and Katsina and Sokoto states shows a reliability of 0.86 and 0.72 respectively. The probability frequency distributions for the two states are moderately flatter than a normal distribution curve, with tail skewed to the right, i.e. the period of high radiation incident. The performance of the radiation data were tested using a 250W PV panel and Sokoto state shows a total solar power of 35,556.00 kWh and that of Katsina state is 36,033,47 kWh considering the total surface area of the states.

References

1. Abubakar, G., Gwani, M., NaAllah, M., & Musa, A. (2015). Wind Power Potential Analysis of Sokoto Northwestern Nigeria. *International Journal of Chemical and Environmental Engineering*, *6*, 369–373.

2. Akinbulire, T. O., Oluseyi, P., & Babatunde, O. (2014). Techno-economic and environmental evaluation of demand side management techniques for rural electrification in Ibadan, Nigeria. *International Journal of Energy and Environmental Engineering*, *5*(132), 375–385.

3. Al-Ghussain, L. (2019). Global warming: review on driving forces and mitigation. *Environmental Progress & Sustainable Energy*, *38*(1), 13–21.

4. Aliyu, A. K., Modu, B., & Tan, C. W. (2018). A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. *Renewable and Sustainable Energy Reviews*, *81*, 2502–2518.

5. Aliyu, A. S., Ramli, A. T., & Saleh, M. A. (2013). Nigeria electricity crisis: Power generation capacity expansion and environmental ramifications. *Energy*, *61*, 354–367.

6. Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2014). Solar energy applications and development in Nigeria: Drivers and barriers. *Renewable and Sustainable Energy Reviews*, *32*, 294–301.

7. Uyigue, E., Agho, M., & Edevbaro, A. (2008). National dialogue to promote renewable energy and energy efficiency in Nigeria. *Community Research and Development Centre (CREDC)*.