Evaluation Of Solar Energy Potentials In Northeast Sub-Region Of Nigeria

Mustapha Kunduli
Department of Electrical of Electronic Engineering
University of Maiduguri
Maiduguri Borno State, Nigeria
kunduli@yahoo.com

Bukar Adam
Department of Electrical of Electronic Engineering
University of Maiduguri
Maiduguri Borno State, Nigeria
Adambukar36@yahoo.com

Aliyu, U. O.
Department of Electrical of Electronic Engineering
Abubakar Tafawa Balewa University
Bauch State, Nigeria
uoaliyu@yahoo.com

Jiya, J. D.
Department of Electrical of Electronic Engineering
Abubakar Tafawa Balewa University
Bauch State, Nigeria
Jibjiya27@gmail.com

Bakare, G. A.
Department of Electrical of Electronic Engineering
Abubakar Tafawa Balewa University
Bauch State, Nigeria
gabakare@atbu.edu.ng

Musa Mustapha
Department of Electrical of Electronic Engineering
University of Maiduguri
Maiduguri Borno State, Nigeria
musamustyy@unimaid.edu.ng

***Abstract*—To establish solar energy as the main source of electrical energy in North-eastern part of Nigeria, it is crucial to conduct a comprehensive and thorough analysis of its potential. This analytical approach would significantly enhance the development of solar energy generation at both regional and national level. In this study, the solar energy potentials of the entire sub-region were evaluated and statistically characterized using ten-year data obtained from National Aeronautic Space Agency (NASA) global database. Applying relevant statistical analysis on the solar energy data collected, this sub-region is confirmed to have the highest range of 7.26kWh/m2/day to 10.64kWh/m2/day solar irradiation profile for the entire Nigerian landmass. To illustrate the huge solar energy resource potential of this sub-region, 0.05% of its landmass can produce 43.73TWh/annum of electrical energy.**

Keywords— Solar energy; Global Database; Northeast Sub-Region; Characterization; Statistical Analysis

I. INTRODUCTION

To secure a sustainable future and combat the escalating effects of climate change, particularly global warming, developing countries are prioritizing a swift transition from conventional energy sources to renewable alternatives[1]. Solar energy is replenished, cost-free, and environmentally friendly, making it one of the most attractive options among renewable energy sources. Over the past decade, the global solar PV market has expanded by 50% at a remarkable pace[2]. The assessment of solar energy prospect relies on a range of multidimensional factors, including, but not limited to, regional solar energy resource, land size, advancements in technology, the cost-effectiveness of solar products, and government strategies. Each of these elements significantly influences the growth of the solar energy deployment [3]. Among these, land size plays a critical role in identifying suitable locations for installing solar PV systems [4]. Technological advancements are crucial for determining the efficiency of solar energy conversion [5], which, in turn, affects the economic viability of solar power generation. Furthermore, government policies have been recognized as essential to the successful operation of solar PV systems [6]. Given these considerations, a thorough analysis of solar energy potential must account for not only the availability of solar energy resources but also technological, economic, and other related factors. A holistic evaluation should focus on identifying key factors for successful solar PV installation while minimizing both construction and operational expenses [7].

Researchers regularly propose new systems to support our society's dire need for an alternative to fossil fuel energy sources photovoltaic (PV) energy is not necessarily new[8],[9]. PV systems utilize sunlight to generate electricity through semiconductor PV cells. The particles of light (photons) strike the surface of the cells, releasing negatively charged particles (electrons) from the cells atoms, which causes electric flow[9]. Humans have been harnessing solar energy for centuries and advancements have been made ever since. By acknowledging PV systems journey through history, we reveal the benefits of going solar, the various types of PV system options, and the costs associated with them [10],[11].

The North-East sub-region of Nigeria has numerous untapped energy resources that encompass majorly renewable energy sources and, to some limited extent, conventional energy sources. The missing gap, however, is how best to deploy the viable energy resources to tap sustainable economic potentials of the sub-region. This will, naturally, call for the development of credible energy resource database for their management and optimal utilization for decentralized power generation to meet the needs of various underserved communities.

A well-researched energy resource database for the entire north-east sub-region is not readily available and this is without prejudice to the existing research investigations on identified energy resource entities in some specific localities of north-east sub-region. For the avoidance of doubt, the various available energy resources in the North-East sub-region include solar, hydro, biomass (agro waste), wind and emerging discoveries of fossil fuels but lack in-depth evaluation from utilization sustainability standpoint.

The main focus of this paper is to present a viable road map for the utilization of the indigenous energy resources, in coordinated manner, for sustainable distributed power generation applications in the North-East sub-region. The main task was to carry out comprehensive evaluation and characterization of different energy resource potentials in northeast sub-region of Nigeria. The overriding goal concerns sustainable electricity productions for plethora of geographically dispersed rural communities, across the entire northeast sub-region, that currently lack electricity delivery from the national grid.

The prime aim is to evaluate and characterize solar, energy resource potentials in the North-East sub-region of Nigeria for sustainable electricity generation. The key objectives were to develop the short to long-term solar irradiance for the entire North-East sub-region of Nigeria based on ten-year raw data obtained from NASA data web site. This paper is limited to solar data collection from North-East sub-region of Nigeria and will be subjected to in-depth evaluation and characterization for sustainable electricity generation in rural communities.

Statistical and numerical techniques was employed to carry out the analysis of the various data collected to identify viable energy resources for purpose intended in each state of the north-east sub-region. The computations of leading design parameters of viable energy resources will be carried out for all the north-eastern states.

The authors in [12] investigated the impact of local weather variables on solar and wind power systems. In their findings, solar power and wind power can compensate well for one another and can provide a good capacity factor for hybrid renewable energy applications. The authors in Ref. [13] examined the solar power potential of India by incorporating land-use factors and the solar-to-electric conversion efficiency of PV modules. [14] explored the prospect of solar of municipal housing buildings by evaluating resource availability, technical capabilities, and economic viability to enhance solar energy utilization. The authors in [15] utilized Geographic Information Systems to assess the feasibility of rural solar energy potential in West Africa. Their study revealed that the technical potential for concentrated solar power production ranges from 700 to 1800 TWh/year, while solar photovoltaic systems offer a potential between 900 and 3200 TWh/year. These findings provide a theoretical basis for governments, NGOs, private investors, and other stakeholders to pinpoint suitable regions for solar power development in West Africa. The authors in [16] conducted studies on estimating diffuse solar radiation for Yola, located in Adamawa State, North-Eastern Nigeria. The authors in [17] and [18] highlighted that the intensity of solar radiation at any location is affected by atmospheric factors, as solar radiation undergoes attenuation while traveling through the Earth's atmosphere.

Nigeria is situated in a high sunshine belt of the tropics and thus has enormous solar energy potentials. Nigeria also exhibits cold and dusty atmosphere which is experienced during the harmattan in the northern part and usually occurs for four months period (November to February) annually [19]. The dust from the harmattan exhibits scattering impact on the solar radiation intensity. Based on extensive literature survey carried out, it has been established that there is no comprehensive and reliable assessment of technically viable renewable energy resources in the northeast sub-region. The identified gap has motivated this effort to embark on assessment of solar energy potentials for sustainable distributed electricity generation schemes to mitigate energy poverty in north-east sub-region. Finally, temporal, and spatial based statistical characterizations of solar energy potentials in the study area. Subsequent subsections that follow will present each of the methodologies successfully developed and implemented.

II. Ease of Use

This section presents comprehensive documentation of the materials and methods deployed to realize the aim and objectives of this paper. The data collection procedures are anchored firstly on structured survey-based studies to enable collection of long-term collection of solar radiation data from National Aeronautics and Space Administration (NASA) website. Different methodologies are developed: to carry out statistical characterization and energy potential derivable from solar energy for the northeast sub-region. The integral components of materials and methods are set forth in the subsequent sections that follow in sequel.

A. Materials

Long-term monthly solar irradiation data were collected in the northeast sub-region of Nigeria. More specifically, Ten-year (2009-2018) monthly average solar irradiation data were downloaded from NASA website and used to determine the energy potentials of the energy source entertained for the entire study area.

The computer made use in this work was Dell with Pentium (R) Dual Core CPU, 2.2 GHz Processor and having RAM memory of 4GB and 40GB Hard disk memory storage. The software packages deployed for large data processing, computational solution of formulated mathematical problems, etc. comprised the following, amongst other software codes developed for different scenario studies: Excel spreadsheet for large data analytics; MATLAB software tools for computational solution; Origin 50 for bad data detection, data gaps, etc.; and C++ and FORTRAN programming Languages. The utilization of the foregoing software tools to implement methodologies delineated in the next section is central to accomplishing the research objectives. Solar irradiation data were downloaded from NASA website and used to determine the energy potentials of the energy source entertained for the entire study.

B. Methods

This subsection was devoted to theoretical analysis of solar energy potential in the northeast sub-region comprising six states. For the sake of generalization, consider an arbitrary study area comprising n contiguous states. The entire study area is divided into M cell areas where i^{th} state has M_i area cells $i = 1,2 \ldots, \ldots n$ such that $\sum_{i=1}^{n} M_i = M$ the land mass of i^{th} state is then given by $A_i = \sum_{k=1}^{M_i} a_k^{(i)}$ and $a_k^{(i)}$ is the k^{th} cell area dimensioned $L \times L\ (m^2)$.The cell area was carefully chosen to justify the assumption of uniform solar irradiance received within it. Fig. 1 illustrates northeast land mass divided into fairly large number of cell areas.

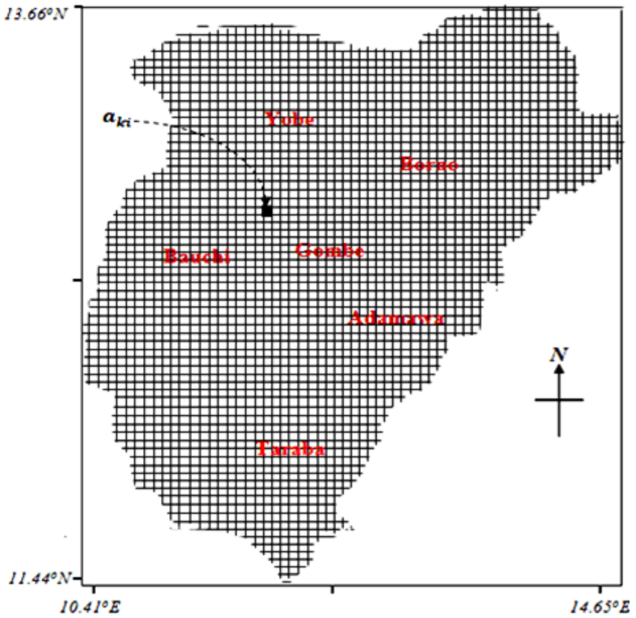

Figure 1: Northeast Sub-region Showing Cell Areas with Constant Solar Irradiance

Solar energy potential estimation

Ideally, each cell area allocated to each state within the study area ought to have a dedicated pyranometer for global solar irradiance measurements as well as dedicated anemometer for wind speed measurements. However, the practical scenario is that some selected locations in a given state would have weather monitoring stations built with provisions made for the hourly monitoring of solar irradiance

The availability of daily or monthly mean irradiance data is critical for the assessment of their technically feasible energy potentials. Herein, the relevant equations developed for pragmatic estimation of solar energy potentials for each state in the study area are set forth in the subsections that follow.

D. Solar energy potential characterazation

The solar energy potential of state i considering spatial variation of solar irradiance between k^{th} and $(k+1)^{th}$ cell areas is given by Eqn. 1. h

$$\mathbb{E}_{ip_{solar}} = \sum_j \left(\sum_k G_k^{(i)} \times \phi_k^{(i)} \times a_k^{(i)} \times \xi_{jk}^{(i)} \right) \quad i = 1,2,..n \qquad (1)$$

Were

$G_k^{(i)}$: Average solar irradiance in kW/m^2 for cell area $a_k^{(i)}\ (m^2)$ of state i;

$\phi_k^{(i)}$: Micro-climatic index factor on solar irradiance received in k^{th} cell area of state i.

$\xi_{jk}^{(i)}$: Being the available sunshine hours in j^{th} day of the year for the k^{th} cell area in state i;

$\mathbb{E}_{ip_{solar}}$:Theoretical solar energy potential per annum for state i

The theoretical solar energy potential per annum, for the study area is therefore given by:

$$\mathbb{E}_{p_{solar}} = \sum_{i\epsilon\{1,n\}} E_{ip_{solar}} \times 10^{-3} \ \ MWh \qquad (2)$$

Where;

$\mathbb{E}_{p_{solar}}$: Total solar energy potential per annum for n contiguous states of the study area.

The average theoretical daily solar energy density $\partial_{i_{solar}}$received in state i and the study area $\partial_{SA_{solar}}$can now be respectively expressed thus:

$$\left.\begin{aligned} \partial_{i_{solar}} &= \left(\frac{\mathbb{E}_{ip_{solar}}}{A_i \times N}\right) \times 10^{-3} \ MWh\, m^{-2} day^{-1} \quad i \in \{1, n\} \\ \partial_{SA_{solar}} &= \left(\frac{\mathbb{E}_{p_{solar}}}{\left(\sum_{i\epsilon\{1,n\}} A_i\right) \times N}\right) \times 10^{-3} MWh\, m^{-2} day^{-1} \end{aligned}\right\} \qquad (3)$$

Where N is the calendar days per annum, which is either 365 or 366 depending on whether it is non-leap year or leap year.

In order to sustain distributed electricity generations, will demand for a small fraction of the total landmass of the study area to harness the solar energy. Let $0 < \gamma_i < 1$ be the fraction of landmass contribution from the i^{th} state for electricity generation in the study area. Thus, the gross electricity generated from solar energy harnessed from the n states is given by

$$\mathbb{E}_{SA_e} = \left[\sum_{i=1}^{n}\left(\gamma_i \times E_{ip_{solar}}\right)\right] \times \eta_e \times 10^{-3} MWh_e \quad (4)$$

Where;

$\mathbb{E}_{SA_e}$: Gross electricity generated from the solar energy source.

η_e: Efficiency of direct conversion process utilizing photovoltaic arrays and is typically between 12% and 15% depending on the solar cell technology choice (mono- and polycrystalline silicon).

The solar based electricity generation contribution from the i^{th} state: $\mathbb{E}_{i_e} = \gamma_i \times E_{ip_{solar}} \times \eta_e \times 10^{-3} MWh_e$. The foregoing equations are central to harnessing distributed power generation schemes from solar energy towards mitigation of energy poverty in the northeast sub-region.

It is intuitively clear that land availability is the starting point in the development of solar energy-based power generation schemes. For the avoidance of doubt, it is postulated that land availability in the northeast sub-region is not a major constraint most especially in the rural areas where green electricity development is deemed desirable. Consequently, solar energy-based applications in northeast sub-region are found to be technically feasible due to high sun hours and solar irradiations, notwithstanding the micro-climate impacts such as dust laden harmattan season, inclement weather condition, etc.

E. Design of distributed solar PV farms

Let us consider electricity productions from solar energy utilizing direct energy conversion process via installations of distributed PV arrays in the study area. Assume that there are N_i solar PV farms in i^{th} state, each j^{th} farm rated $P_j^{(i)}$ kW, either for meeting electricity requirements of remote clusters of rural communities or to be integrated with an existing electric `utility. Let all the installed PV arrays in state i and bearing optimum orientation for maximum energy harvest have total area of $A_{i_{PV}}$ given by:

$$A_{i_{PV}} = \sum_{j=1}^{\mathrm{N}_i}\left(\frac{P_j^{(i)}}{\left(\eta^{(T)} \times \widehat{G}_{ij}^{(\ell_j)}\right)}\right)(m^2) \quad i = 1,2, \dots n \quad (5)$$

Where;

$\eta^{(T)}$: Conversion efficiency of PV with superscript T denoting technology type: mono or poly-crystalline and $\widehat{G}_{ij}^{(\ell_j)}$: Solar Irradiance (kWm^{-2}) defined as average irradiance value for j^{th} solar PV farm in state i sited on ℓ_j cell areas of land.

Let $\widehat{G}_i$ be the weighted average solar irradiance for state i defined mathematically as $[\sum_{j\in\{1,\mathrm{N}_i\}}(\widehat{G}_{ij}^{(\ell_j)} \times \ell_j)]/[\sum_{k\in\{1,\mathrm{N}_i\}} \ell_j]$. The total electrical power output from all PV farms in state i is expressed as follows taking into account derating factors for micro-climatic conditions and PV panel operating temperatures:

$$P_{i_{PV}} = A_{i_{PV}} \times \eta^{(T)} \times \widehat{G}_i \times \Upsilon_{mc_i} \times \Upsilon_{Temp_i}; \quad (6)$$

$$i = 1,2, \dots . n$$

Where;

Υ_{mc_i} is micro-climate derating factor and Υ_{Temp_i} is panel operating temperature derating factor. These derating factors are site specific and must be determined from experimental measurements and analysis. Broadly speaking, the derating factors are less than unity with implication of reduction in power outputs of the distributed solar PV farms.

The overall power output of PV farms installed in the study area become:

$$P_{SA_{PV}} = \sum_{i=1}^{n} P_{i_{PV}}(T, mc, \eta, G) \leq \sum_{i=1}^{n}\sum_{j=1}^{\mathrm{N}_i} P_j^{(i)}(NOCT, STC) = P_{SA_{PV}}^{Rated}\ (kW) \quad (7)$$

Where;

$P_{SA_{PV}}^{Rated}$: is the overall rating of all solar farms designed for the study area. Note that the nameplate ratings of PV panels are based on standard test condition (STC) at nominal operating cell temperature (NOCT) of 20°C. Under field operating conditions, PV modules power outputs can only be expected to be less than their rated values due to different operating temperatures, cloud overcast and dust laden.

F. Statistical analysis of solar energy data for the study area

The availability of long-term solar energy data for the study area is starting point to engender firstly preprocessing algorithm to secure data integrity, devoid of bad and/or missing data gaps. The long-term data implied could be derived from satellite weather databases on the study area or on-site distributed weather monitoring stations. As the main computational engine of data preprocessing algorithm, we propose a combination of raster plots of sequentially segregated data blocks to remove any outliers and deployment of weighted moving average technique to fill-in identified missing data-gaps. The principal reason for embarking on data preprocessing is to secure improved data integrity and accuracy. This is a sine qua non to achieving very sound assessment of solar energy harvest for cost-effective electricity generations.

The post-processing of solar irradiation data for the study area entails statistical computations of their averages, variances, modes and medians, minima, maxima denoted respectively by $\bar{x}, s^2, Mo, Md, Min$ & Max, for different locations. For a given data sample $\{x_1, x_2 \dots \dots x_i, \dots \dots \dots x_N\} \in \mathcal{R}^N$, the generalized expressions for the statistical parameters are as follows.

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i\,; \quad s^2 = \frac{1}{N-1}\left(\sum_{i=1}^{N}(x_i - \bar{x})^2\right) \tag{8}$$

$$Mo = Most\ frequent\ number\ of\ \{x_1, x_2 \dots \dots x_i, \dots \dots \dots x_N\}$$

$$Md = Center\ number\ of\ numerically\ ordered\ \{x_1, x_2 \dots \dots x_i, \dots \dots \dots x_N\}$$

$$Max = Maxmum\ \{x_1, x_2 \dots \dots x_i, \dots \dots \dots x_N\}$$

This research work relied principally on ten-year monthly irradiation sourced from NASA global databases as well as monthly irradiation data obtained from NiMeT supplemented by recent publications on solar characterizations for selected locations in the study area. The salient steps adopted in the analysis of ten-year data for solar radiation for each state in the northeast sub-region of Nigeria are depicted in the comprehensive flowchart of Fig. 2. In the next section, we present the results obtained based on the methodologies developed herein.

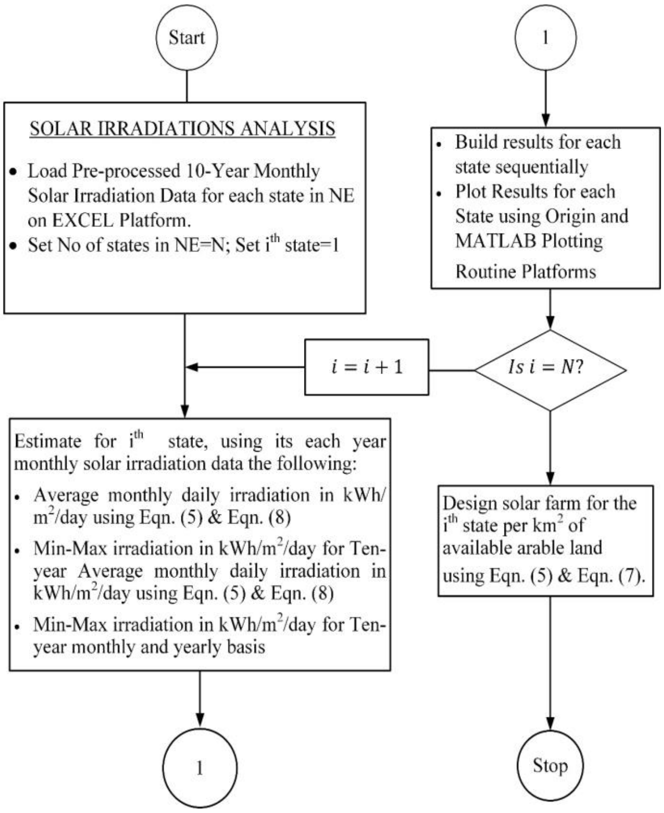

Figure 2: Functional Flowchart for Solar Energy Statistical Analysis

III. RERSULTS AND DISCUSSION

Solar energy being, unarguably, one of the abundant renewable energy sources in the Northeast region of Nigeria has been subjected to statistical analysis and modeling; considering each state within the sub-region. We reiterate that the results provided herein made use of 10-year monthly data for the sub-region downloaded from NASA website and NiMeT data for some specific locations. We present in-depth analyses of solar energy to highlight the abundance of this renewable resource in this sub-region-far more than other sub-regions in Nigeria.

Relying on Excel platform, computations of mean solar irradiations for ten-year (2009 - 2018) benchmark data have been carried out for each state in the northeastern Nigeria for different scenarios; involving running mean monthly-daily solar irradiations for each year and then over ten-year duration

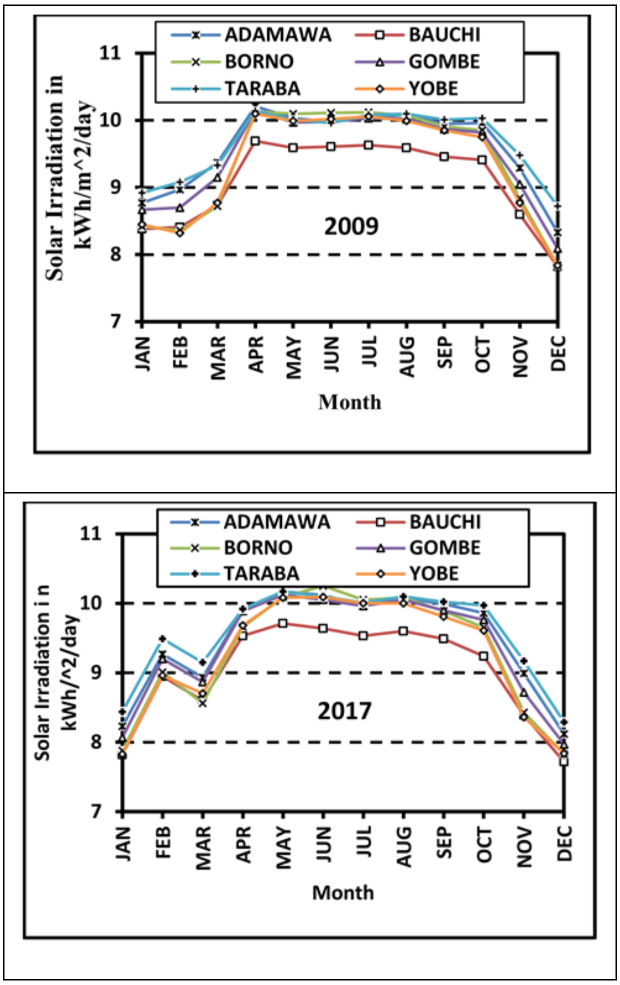

Figure 3: Monthly Mean Daily Solar Irradiations for Six NE States for Two Selected Years For carefully selected two years (2009 and 2017), Fig. (3) depicts the corresponding composite plots of monthly-daily solar irradiations for the six states. In order to further elucidate the solar energy variability in northeast sub-region, Figs (4) and (5) show the mean monthly daily and mean yearly daily solar irradiations, respectively for the six northeast states. Table 1 in Appendix presents results of min-max solar irradiation values for each state mined from 10-year solar irradiations data.

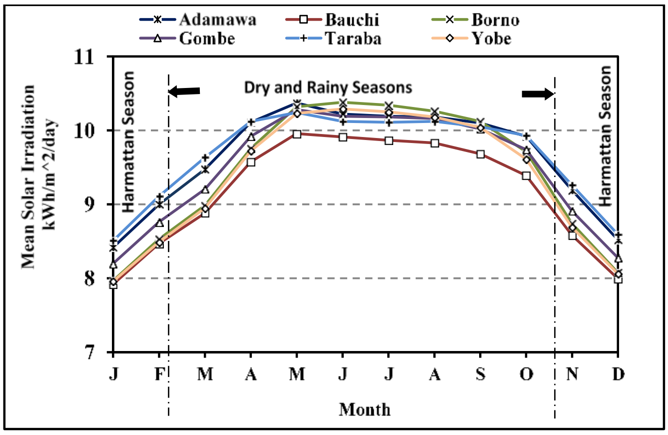

Figure 4: Monthly Mean Daily Solar Irradiation for Six NE States Using 10-Year Solar Data

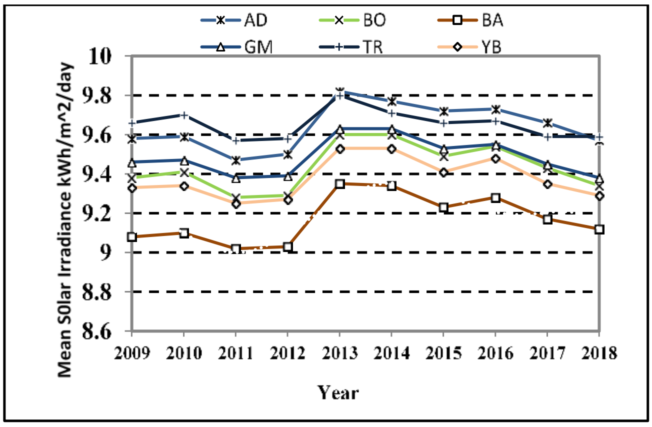

Figure 5: Yearly Mean Daily Solar Irradiation for Six NE States from 2009 to 2018

. Fig. 5 depicts the min-max plots of solar irradiations for the states. Relying on foundation data of Table 1, solar energy per annum harvestable from 0.05% of each state landmass is presented in Table 2. Fig. 6 shows plot of annual electrical energy potential per allowable 0.05% of each state landmass for PV farms of mono-crystalline technology at efficiency of 12% and net conversion efficiency of 80% using PV calculator.

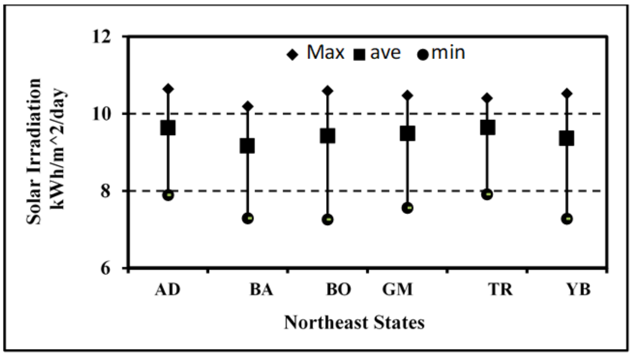

Figure 5: Min-Max Plot of Solar Irradiation for Six NE States Based on 10-Year Solar Data

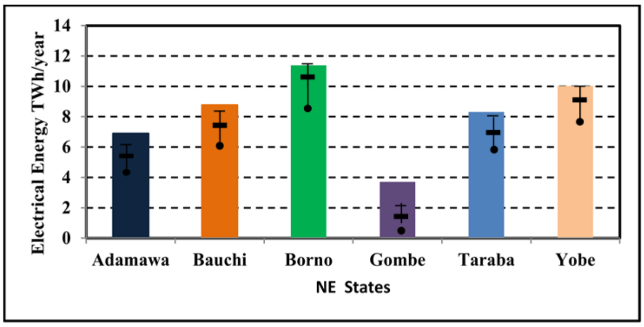

Figure 6: Comparison of Electrical Energy Potential from Solar Farms in NE States

IV. Discussion

Solar energy remains the most abundant renewable energy sources in the northeast sub-region of Nigeria. Referring to Fig. 2, two years, 2009 and 2017, have been selected for detailed statistical analysis of monthly daily variation pattern of solar irradiation in six states of northeast. It is seen that solar monthly daily irradiations are much higher in the months of March to October that span dry and rainy seasons than the rest of the months of the year corresponding to Harmattan season. The effect of climate variation between the two selected years is quite apparent especially during the Harmattan period. The ten-year based statistical analysis of monthly daily irradiation pattern of Fig. 2 further corroborates the inherent seasonal variability exhibited in Fig. 3 for the six NE states; whilst their mean yearly daily solar irradiations fall between 9kWh/m^2/day and 9.8kWh/m^2/day as deduced from Fig. 5.

To further deepen the statistical characterizations of the enormous solar energy potentials in all the northeastern states, led to compendium of far-reaching results presented in Table 1 and Table 2 (see Appendix) with their respective graphical illustrations in Fig 5 and Fig. 6. Relying on Table 1 and benchmark data published by ECN, it is established that northeast sub-region returned the highest range of 7.26kWh/m^2/day to 10.64kWh/m^2/day solar irradiation profile for the entire Nigerian landmass. It is also noteworthy from Table 2 that only 0.05% of its landmass per state dedicated to solar harvest is capable of generating 461.42 TWh/annum from distributed PV farms based ‘green’ electrical energy.

V. Summary and Conclusion

Solar energy potentials have been evaluated and statistically characterized using ten-year data obtained from NASA global database. The sub-region is confirmed to have the highest range of 7.26kWh/m^2/day to 10.64kWh/m^2/day solar irradiation profile compared with other sub-regions of Nigeria. The annual mean solar radiation as indicated in the results that all the six states, though the two states Taraba and Adamawa states are marginally higher in solar radiation have very close solar radiation pattern and are capable of generating electricity to some parts of the study area. To illustrate the huge solar energy resource potential of this sub-region, 0.05% of its landmass can produce 43.73TWh/annum of electrical energy. The solar energy potentials in the entire NE sub-region both in depth and depth beyond previously done. It has been conclusively established that NE sub-region has the highest range of 7.26kWh/m^2/day to 10.64kWh/m^2/day solar irradiation profile for the entire Nigerian landmass. To illustrate the huge solar energy resource potential of this sub-region, 0.05% of its landmass can produce 43.73TWh/annum of electrical energy.

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Appendix

Table 1: Min-Max Monthly Daily Solar Irradiation Values for Six Northeast States Based on 10-Year Solar Data

NE States	Solar Parameter Specifications	Yearly Solar Irradiation Parameter Values (kWh/m²/day)										10-Year Values of Min., Ave. & Max (kWh/m²/day)
		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Adamawa (AD)	Minimum	8.33	8.37	8.12	8.12	8.82	8.54	8.34	8.33	8.64	8.89	8.12
	Average	9.58	9.59	9.47	9.50	9.82	9.77	9.72	9.72	9.66	9.57	9.64
	Maximum	10.21	10.28	10.17	10.09	10.58	10.56	10.64	10.55	10.46	10.32	10.64
Bauchi (BA)	Minimum	7.82	7.92	7.72	7.86	8.24	7.96	7.62	7.61	8.01	7.29	7.29
	Average	9.08	9.10	9.02	9.03	9.35	9.34	9.23	9.28	9.17	9.12	9.17
	Maximum	9.69	9.76	9.71	9.64	10.19	10.19	10.14	10.16	10.19	10.13	10.19
Borno (BO)	Minimum	7.84	7.81	7.83	7.81	8.29	8.08	7.63	7.73	8.13	7.27	7.27
	Average	9.37	9.40	9.28	9.29	9.60	9.59	9.48	9.54	9.43	9.34	9.43
	Maximum	10.13	10.36	10.25	10.17	10.5	10.54	10.59	10.52	10.51	10.44	10.59
Gombe (GM)	Minimum	8.09	8.2	7.97	8	8.5	8.3	7.89	7.93	8.35	7.56	7.56
	Average	9.46	9.47	9.38	9.39	9.63	9.63	9.52	9.55	9.45	9.37	9.49
	Maximum	10.15	10.18	10.12	10.08	10.47	10.46	10.4	10.47	10.41	10.25	10.47
Taraba (TR)	Minimum	8.72	8.71	8.29	8.35	8.89	8.5	8.21	8.31	8.53	8.91	8.21
	Average	9.66	9.70	9.57	9.58	9.79	9.70	9.66	9.67	9.58	9.59	9.65
	Maximum	10.14	10.27	10.17	10.1	10.38	10.37	10.4	10.39	10.28	10.26	10.4
Yobe (YB)	Minimum	7.84	7.8	7.83	7.77	8.26	8.08	7.66	7.66	8.11	7.28	7.28
	Average	9.33	9.33	9.25	9.27	9.52	9.52	9.40	9.47	9.35	9.28	9.37
	Maximum	10.1	10.22	10.09	10.1	10.4	10.44	10.52	10.47	10.44	10.38	10.52

Table 2: Solar Energy Intercepted by 0.05% landmass of each NE State and NE Sub-region

Classification of Solar Energy Intercepted	Solar Energy Intercepted by each State (TWh/yr)						Solar Energy Intercepted by NE (TWh/yr)
	Adamawa (18.5km²)	Bauchi (24.6km²)	Borno (30.7km²)	Gombe (10.1km²)	Taraba (22.1km²)	Yobe (27.2km²)	
Maximum	71.85	91.5	118.67	38.6	86.55	104.44	511.61
Average	65.09	82.34	105.67	34.98	80.31	93.03	461.42
Minimum	54.83	65.46	81.46	27.87	68.32	72.28	370.22