VOL. 03 NO. 5,
FEBRUARY, 2024
E-ISSN 3027-1339
P-ISSN 3026-8257



African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Systematic, Evaluation and Diversity Engr. (JSEDE)

Assessment of Solar Energy Potentials of North-Eastern Region of Nigeria

Muhammad Ismaila Yahuza; & Engr. Muhammed B. Suleiman

Department of Electrical & Electronics Engineering Technology, Federal Polytechnic Bali, Taraba State.

Abstract

Nigeria is one among developing countries facing the highest energy crises in the world. Within Nigeria, the North-East region is the region with the lowest average energy consumption and access to grid electricity despite having abundant Renewable Energy resources. This paper estimates the potentials of solar energy for electricity generation in the North-East region. The North-East region has enormous amount of solar energy which is yet to be tapped. The renewable energy industry in the sector of energy generation holds great promise, particularly in the North-Eastern Zone of Nigeria, where the states of Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe exhibit substantial potential. It was found that all the states in the North-East region have the potentials for generating electricity from solar PV technology. This study shows that the region was estimated to be able to generate about 356,668.64 MW of electricity from PV technology. Though the potential for generating electricity through solar PV technology is enormous in the North-East, the investment cost is one of the major hindrances. There is high cost of PV panels and backup batteries which serves as a hindrance to the generation of electricity from solar energy. Also, there is low level of public awareness on the availability and usefulness of solar energy in the region. The generation of electricity from PV technology is key to the socio-economic and sustainable development of the North-East region. It is advised that flexible policies which will make the environment suitable for local and foreign investors be made so that the enormous amount of

untapped solar energy of the region can be utilized to benefit the region, and the country in general.

Keywords: Renewable Energy, Solar Energy Potential, and North-Eastern Nigeria.

Introduction

Background

The North-East region is the region with the lowest average energy consumption and access to grid electricity despite having abundant Renewable Energy resources. This study estimates the potentials, challenges as well as prospects of solar energy for electricity generation in the North-East region. The North-East region has an enormous amount of solar energy which is yet to be tapped. It was found that all the states in the North-East region have the potentials for generating electricity from solar PV technology looking at the abundant solar radiation in the region[1]. Though the potential for generating electricity through solar PV technology is enormous in the North-East, the investment cost is one of the major hindrances. There is a high cost of PV panels and backup batteries which serves as a hindrance to the generation of electricity from solar energy. Also, there is low level of public awareness on the availability and usefulness of solar energy in the region[2]. The generation of electricity from PV technology is key to the socio-economic and sustainable development of the North-East region. There is need to harness the estimated potentials for solar energy generation in the region to enable both local and foreign investors to fully invest in the region. If flexible policies which will make the environment suitable for local and foreign investors are made, the enormous amount of untapped solar energy of the region can be utilized to benefit the region, and the country in general.

Energy Scenario Nigeria and the North-Eastern Region

Nigeria, located in West Africa, is a country with a rich and diverse energy environment. Understanding the background and energy picture of Nigeria includes examining historical, economic, and geographical aspects that have shaped its energy business. Nigeria's energy industry has transformed considerably throughout the years. Historically, the country mostly relied on conventional biomass for its energy needs. However, with the discovery of oil in the Niger Delta area in the 1950s, Nigeria experienced a huge shift in its energy focus[3]. Oil rapidly became the main energy source, changing the country into a vital player in the global oil market. Despite being a big oil exporter, Nigeria experiences energy challenges, including

an inconsistent electrical supply. The energy mix is vast, consisting of fossil fuels, hydroelectric electricity, and renewable sources[4]. Oil and natural gas contribute greatly to the country's energy output, with hydroelectric electricity playing a vital part as well. In recent years, there has been a greater emphasis on employing renewable energy sources to diversify the energy mix and promote sustainability[5]. Nigeria's energy sector grapples with several challenges[6].

The North-East area of Nigeria, containing states such as Borno, Adamawa, and Yobe, has a distinct backdrop and energy landscape created by both historical influences and modern difficulties. The North-East area has a diversified cultural past, with agriculture traditionally being an important economic sector. Historically, the energy demands were fulfilled by conventional sources including biomass, wood, and animal waste[10]. The region also experiences the consequences of intermittent violence, hurting energy infrastructure and access. The North-East area has been seriously affected by the insurgency led by Boko Haram. This has not only disturbed daily living but also impeded the construction and maintenance of essential energy infrastructure. Frequent attacks on power infrastructure and the relocation of residents contribute to the difficulty encountered by the region in constructing a stable and sustainable energy system[12]. Despite hurdles, there are continuous attempts to improve the energy picture in North-East Nigeria. Renewable energy sources, notably solar electricity, are being studied to provide decentralized and off-grid options[13]. These programs attempt to boost energy availability in rural regions and contribute to the region's resilience against outages caused by wars. The energy scenario in North-East Nigeria has direct repercussions for the economic and social well-being of its population. Limited availability to reliable electricity impacts economic operations, education, and healthcare. Addressing these difficulties is vital for supporting economic development and enhancing the general quality of life in the region[14].

The backdrop and energy picture of North-East Nigeria are distinguished by historical reliance on conventional sources, problems posed by war, and continuous efforts to incorporate sustainable and renewable energy alternatives[10].

Research Objectives

i. To establish familiarity with the data and geography of solar radiation in the North-East region,
ii. To use ArcGIS software to map locations for obtaining global solar radiation in the six states of the North-East region.
iii. To use a 300W/24v PV module and Pyranometer with Data Logger, to measure the available power based on global solar radiation in real time, with specified module tilt and orientation.

iv. To use the available output power obtained to estimate the total solar energy potential of each state in the North-East region.

Significance of the Study

The study on the evaluation of solar energy potentials in North-East Nigeria is of fundamental relevance, indicating a pivotal step towards sustainable and resilient energy practices in the region. It tackles the important need for diversification in the energy industry, proposing a roadmap to minimize reliance on traditional sources and shift towards renewable alternatives. By tapping into the rich solar resources, North-East Nigeria can boost energy security, reduce environmental effect, and contribute to the worldwide push for sustainable energy practices. This research establishes the framework for a dramatic transition in the region's energy environment, building resilience against traditional energy difficulties and harmonizing with international sustainability goals.

Solar Energy and its Importance

Solar energy is a vital and environmentally friendly kind of renewable energy, which plays a critical role in the promotion of sustainable development. The mentioned energy source is both unlimited and abundant, making it a very feasible choice for generating power and meeting various energy needs. The development of solar energy applications, including concentrated solar power and solar photovoltaics, is constantly progressing to optimize energy output and make major contributions to economic and environmental progress [15]. Solar energy is not only applicable in various fields, but it also has the potential to significantly change the agriculture industry.

The use of solar energy into agricultural techniques is especially important in meeting the increasing need for food supply with population increase. This strategy not only provides a sustainable growth in agricultural productivity but also concurrently mitigates pollution and lowers dependency on traditional fossil fuels. Solar energy in agriculture has several advantages that enhance the development of an ecologically aware and robust food production system [17].

In a larger perspective, solar energy appears as a complete and cost-effective option to solve not only the rising energy requirements but also to battle climate change. Its renewable nature and minimum environmental effect position it as a major actor in the transition towards a cleaner and more sustainable energy landscape. As the world population continues to expand, the application of solar energy solutions becomes vital for establishing a healthy balance between energy security, economic development, and environmental preservation [18].

The diversity of solar energy, spanning uses in power production, agriculture, and beyond, makes it a cornerstone in the goal of a sustainable future. By utilizing the

benefits of solar energy across multiple sectors, communities may make substantial progress towards attaining energy resilience, environmental stewardship, and overall sustainable development.

Solar Energy Potential Assessment

Solar energy potential in Nigeria is being studied through several research. Nigeria has a high potential for solar photovoltaic (PV) systems, with broad solar resources and strong solar energy potential [19]. Solar energy is considered a sustainable and non-depleting energy source that can assist bridge the gap between energy demand and supply in Nigeria [20]. Geospatial approaches have been utilized to study solar energy potentials in several parts of Nigeria, such as Niger State and Akure, Ondo State [21]. These studies have found places with moderate to very excellent solar energy potential, making them suitable for solar energy farms [22]. The findings of these studies have shown the tremendous availability of solar energy potentials in Nigeria and the potential for solar energy to enhance the country's energy supply. Overall, solar energy has been acknowledged as a viable alternative source of energy in Nigeria, with the ability to offer clean and dependable electricity for the country's growth.

Previous Studies on Solar Energy Potentials in Nigeria

The research by [23] studies sun irradiance over climatic zones in Nigeria for solar energy applications. Using satellite-derived data confirmed against ground observations, the research covers five climatic zones. It applies statistical tests for validation and evaluates the frequency distribution of solar irradiation for each zone. The research stresses the relevance of solar radiation data, especially in places with sparse ground stations. The results demonstrate variable solar energy potential throughout temperate zones. The report acknowledges the constraints of limited ground stations but suggests a complete strategy by merging satellite and ground data. The paper continues by underlining the social advantages of earth observation satellites in renewable energy applications.

The research by [24] assesses the life cycle impact of a 1.5 kW solar photovoltaic (PV) system in six geographical areas of Nigeria. The research focuses on measuring the system's life cycle emission rate, global warming potential, cumulative energy demand, energy payback time, and net energy ratio. The research utilizes six diverse sites, each representing one of Nigeria's geographical zones, as case studies. The approaches involve analyzing the performance of the PV system in terms of solar irradiation, efficiency, and other aspects. The results reveal that solar energy potential considerably effects the environmental performance of PV systems. The study underlines the relevance of evaluating a location's solar energy potential in planning

and decision-making for PV systems. The restrictions include assumptions regarding the system's longevity, efficiency, and other aspects. Recommendations underline the necessity for thorough assessment of solar energy potential in the design and implementation of PV systems. In conclusion, the research underlines the influence of geographical considerations on the environmental performance of solar PV systems, underlining the need of location-specific planning and analysis.

The comparative examination of home solar farms with energy storage between the USA and Nigeria tries to address Nigeria's electrical concerns was done by [25]. The study employs a model built by IREQ Hydro-Quebec Research Institute and focuses on issues such as energy storage, solar intensity, and grid reliance. The findings indicate grid power, energy storage, home load, and PV-generated electricity for both sites. The study advises decentralizing governance, considering power setup as a state of emergency, and developing worldwide alliances for help. The report underlines the potential benefits of investing in renewable energy.

Empirical models by [26] play a significant role in projecting global solar radiation potential for sustainable and greener energy uses. These models, along with machine learning techniques and statistical studies, assist estimate daily sun radiation. However, the correctness of these models can be questioned, needing additional improvement. The report underlines the necessity of accurate forecasts for sustainable energy applications and offers further research to develop predictive models and overcome constraints. Therefore, continual study is needed to enhance model performance.

The research by [10] analyzes the techno-economic and environmental sustainability of a projected 6 MW grid-connected solar photovoltaic system in the six northeastern states of Nigeria. Utilizing RETScreen Expert software, the research assesses climatic data, technical viability, economic sustainability, emission reduction, and undertakes a sensitivity analysis. The statistics reveal varied solar radiation among states, with Yobe having the highest capacity factor. Economic study indicates good NPV, IRR beyond the desired rate, and favorable payback periods. The paper underlines the possibilities for solar energy investment in the region, indicating reduced dependency on government hydro and gas-fired power plants. The emission reduction evaluation suggests substantial GHG reduction, and the sensitivity analysis underlines the effect of cost and electricity exported to the grid on project variables. The paper finishes with recommendations for state governments to work with the Rural Electrification Agency for solar energy projects, expecting good socioeconomic and environmental implications.

The energy crisis in Nigeria is a severe issue, with weak economic development, rising unemployment, and energy inadequacies. The serviceability of solar electricity discussed in [27] is a potential answer to this dilemma. Nigeria has 427,000MW of

solar potential, however present electricity output falls short. Implementing solar energy might bridge the energy gap, boost rural electrification, and contribute to environmental and health advantages. However, drawbacks include lack of public awareness and early installation expenses. Increased public awareness, government assistance, and technology improvements are needed to make solar power more economically viable.

The article [28] focuses on solving the problem of diesel generator consumption in Nigeria, suggesting the adoption of home solar PV systems as a sustainable alternative. The research incorporates a cost assessment, comparing the usage of diesel generators with solar PV systems under various situations. Results reveal considerable cost reductions with solar PV systems, particularly when financed. The study underlines the policy implications and the necessity for accessible financing solutions to support the wider adoption of solar PV systems. It continues by noting the potential beneficial influence on power availability, economic growth, and environmental sustainability through the introduction of supportive policies and finance schemes. The publication gives a complete analysis, albeit it does not expressly disclose the methodology applied in the financial evaluation.

Study Area Description

The geographical focus of this research is on the North-East Geopolitical Zone of Nigeria, an expansive territory that contains six states: Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe. The physical coordinates of this zone stretch between Latitude 11.8848 and 7.9867 and Longitude 9.9992 and 13.1520, encompassing a wide and varied environment. This area is distinguished by a patchwork of terrains, ranging from plains to mountainous landscapes, paired with different weather conditions [8]. The socio-economic dynamics inside these states add a degree of complexity to the research, needing a comprehensive grasp of the local environment for more exact and accurate judgments.



Figure 3. 1: Map of Nigeria Showing the Study Locations. Source: [23]

The geographical variety within the North-East Geopolitical Zone adds to variances in sun exposure, weather trends, and land use, all of which play key roles in defining the solar energy potential of the region. By extensively studying these geographical variations, the research attempts to build a rigorous framework for understanding the solar energy environment, accounting for the delicate interplay between geographical characteristics and socio-economic aspects. Understanding the specific qualities of each state within the North-East Geopolitical Zone is vital for the holistic evaluation of solar energy potential [29]. From the broad plains of Adamawa to the various landscapes of Taraba, the research emphasizes the necessity for a careful investigation of the qualities that constitute each state. This thorough methodology guarantees that the research not only catches the broad regional patterns but also goes into the micro-level subtleties that impact solar energy dynamics at the state level.

Data Collection

The data gathering process is developed as a diverse approach, embracing many sources and ways to acquire comprehensive information for a full analysis. The study obtained sun irradiation data from renowned sources, using the knowledge and credibility of organizations such as the National Aeronautics and Space Administration (NASA) and the Nigeria Meteorological Agency (NIMET). These sources give significant insights into solar radiation patterns, establishing a framework for the technical examination of solar energy potential within the North-East Geopolitical Zone.

To supplement satellite-derived information, ground-level data was acquired with Pyranometers strategically positioned in each state of the North-East area. These devices captured real-time solar radiation data, providing a sophisticated knowledge of the actual sun exposure received at ground level. This combination of satellite and ground-level data provides a full and accurate assessment of the solar energy potential, incorporating both macro and micro-level factors[30].

Solar Irradiation Data

The Solar irradiance and the Sunlight Day hours define the potential solar energy that may be created at any certain place. Estimating prospective energy generation from solar radiation might be tasking because of related continual fluctuation and changing dynamics of meteorological conditions [31]. These obstacles are delaying realizing the full potential of solar energy for electrical energy generation. Despite this difference, it has been proved that the minimal solar radiation in any part of Nigeria is feasible for electricity which can meet the daily energy demands for lighting, heating, and powering equipment like computer system, television, and refrigerators [32]. In Nigeria, the principal source of meteorological data is Nigerian Meteorological

Agency (NIMET) which has limited data collection facilities at airports across the country. Most of the airports have inadequate equipment to gather precise solar radiation data since their major interest rests in other meteorological data such as temperature, relative humidity, rainfall for their smooth operation.

Specifically, ArcGIS Software performed a vital role in the spatial evaluation, permitting the mapping of varied places within each of the six states in the North-East Zone, namely Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe. Real-time capture of global sun radiation data at these marked sites was done by the deployment of Pyranometers. Furthermore, the research deployed a 300W/24V Monocrystalline solar module in real-time applications to assess the available power based on global solar radiation, painstakingly considering specified module tilt and orientation characteristics. The incorporation of a Data Logger was important in methodically storing the generated information in the needed manner. The determined output power, a culmination of these meticulous measurements, served as the foundation for assessing the overall solar energy potential within each state of the North-East area. Notably, the research employed a forward-thinking strategy by assuming the deployment of ground-mounted solar modules, carefully employing only 1% of the total accessible landmass in each of the six states. This thorough consideration aimed at assessing the potentials for generating power from solar photovoltaic systems, therefore offering a complete view on the achievable renewable energy possibilities within the North-East Geopolitical Zone.

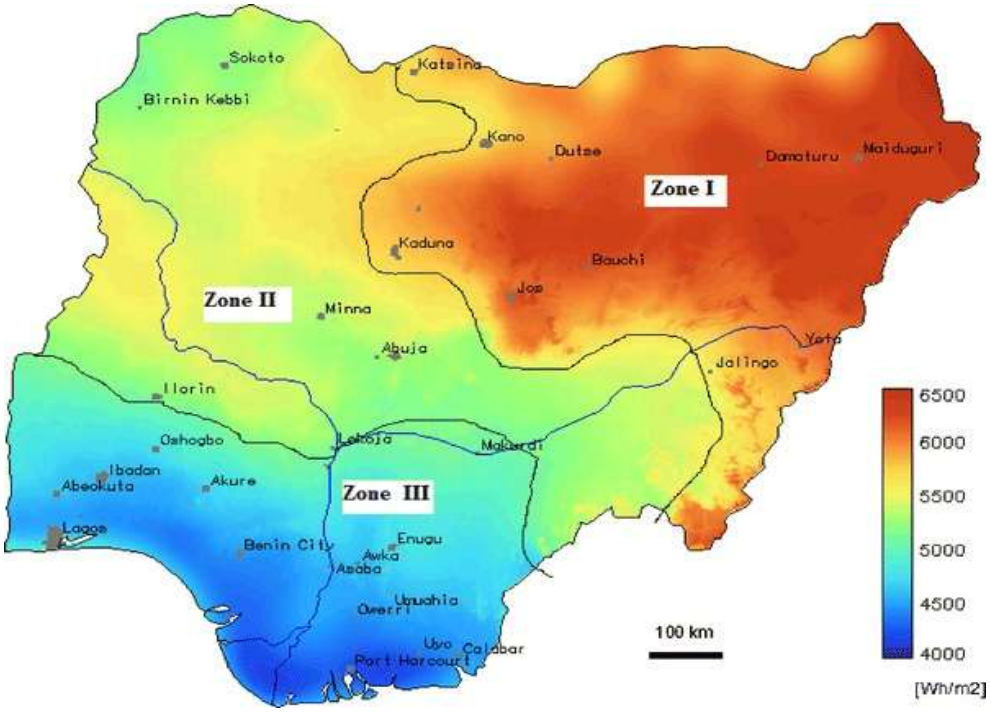


Figure 3. 2: Solar Map of Nigeria Showing Each solar Zone. Source:[1]

The study of solar irradiation data is a careful and comprehensive procedure aimed at deciphering the complicated dynamics of solar energy potential within each state of the North-East Geopolitical Zone. This analytical phase covers a variety of critical steps:
The first phase comprises the measurement of essential solar radiation parameters, including the average daily sun radiation and the clearness index. These factors serve as core measures, offering information about the intensity and purity of sunlight received in the region. Monthly changes in solar radiation were studied to determine patterns and trends, enabling a deeper picture of the temporal dynamics of sun exposure.
To achieve robustness and reliability, the study applies statistical approaches to analyze the complicated information. Statistical methods assist the detection of trends, correlations, and outliers within the sun irradiation data. This statistical inspection adds a degree of quantitative rigor to the investigation, providing a more nuanced understanding of the heterogeneity in solar radiation patterns among various states.

Geographic Information System (GIS) Analysis
The completed research uses ArcGIS software for a comprehensive Geographic Information System (GIS) analysis, delivering an insightful examination into the spatial complexity of sun radiation over the North-East Geopolitical Zone of Nigeria. Through rigorous mapping and visualization, the study effectively depicted the geographical distribution of solar radiation, offering a nuanced knowledge of the solar energy potential within diverse locations. This GIS research played a vital role in finding suitable areas for the deployment of solar energy infrastructure, helping to the strategic planning and execution of sustainable energy programs in the North-East region. The application of ArcGIS proved important in boosting the quality and trustworthiness of the study outputs, offering a firm platform for informed decision-making in the field of renewable energy.

Estimation of Solar Energy Potentials for Electricity Generation
Solar energy can be estimated using the equation shown [34]. This equation estimates the yearly potential electricity generation E (kWh) from a PV system with fixed-mounted modules at selected inclination/orientation, and optionally for dual-axis tracking systems.

$$E = 365 P_K R_P I_h \text{----------(eqn.1)}$$

where $\mathbf{P_k}$ (kW) is the peak power installed, $\mathbf{R_P}$ is the system performance ratio (a typical value for a system with modules from mono- or polycrystalline silicon is 0.75) [34] and $\mathbf{I_h}$ is the monthly or yearly average of daily global irradiation on the horizontal or inclined surface. The system performance ratio of 0.75 estimates system losses 25% as default, where 9% is considered as a 'average' loss owing to temperature impacts and the remaining 16% can be changed by the user.
The power obtainable using 1% of the available land mass from each state is computed using equation 2 below as proposed by [1].

$$E_{1\%} = E\ X\ 1\%\ Available\ Land\ Mass$$----------(eqn. 2)

The results obtained from the above equation is tabulated in table 4.3.

Chapter Four: Data Presentation, Analysis, and Interpretation

Table 4. 1:1Study Locations Showing Latitude, Longitude, and the Available Land Mass

STATE	Longitude (Degrees)	Latitude (Degrees)	Available Land Mass (m^2 X 10^3)	1 % Land Mass (m^2 X 10^3)
Adamawa	**12.4953**	**9.0350**	**36,917,000.00**	**369,170.00**
Bauchi	**9.8324**	**10.3010**	**64,605,000.00**	**646,050.00**
Borno	**13.1510**	**11.8311**	**71,130,000.00**	**711,300.00**
Gombe	**11.1731**	**10.2792**	**18,768,000.00**	**187,680.00**
Taraba	**11.3771**	**8.8927**	**55,920,000.00**	**559,200.00**
Yobe	**11.9662**	**11.7470**	**42,270,000.00**	**422,700.00**

Source: [MACOS Urban Management Consultants]

The current land mass data indicates the space available for solar energy projects in each state if 1% of the total land is used. Despite the significant total land area available, the emphasis on utilizing only 1% highlights the need of optimizing land use for solar energy infrastructure. States with bigger land masses like Borno, Bauchi, and Taraba can support more extensive solar energy projects, considering the 1% usage limit. Policymakers may utilize this data to evaluate the solar energy capacity in each state and develop energy policies that are in line with the land resources at hand. It enables focused investments in solar infrastructure. The little land use (1%) demonstrates a dedication to preserving the environment by keeping most of the land in its natural state. This method can assist in harmonizing energy requirements with ecological conservation.

Table 4. 2: Monthly Average Global Solar Radiation on Horizontal Surface (Ih) with Clearness Sky Index (Kt) for the Study Locations

	ADAMAWA (JIMETA)		BAUCHI (BAUCHI)		BORNO (MAIDUGURI)		GOMBE G(GOMBE)		TARABA (JALINGO)		YOBE (DAMATURU)	
	I_h	K_T	I_h	K_T	I_h	K_T	I_h	K_T	I_h	K_T	I_h	K_T
January	6.31	0.70	6.27	0.69	6.32	0.70	6.24	0.69	6.06	0.63	6.26	0.70
February	6.76	0.70	6.66	0.66	6.78	0.69	6.58	0.67	6.14	0.60	6.65	0.68
March	7.17	0.62	7.23	0.64	7.18	0.62	7.10	0.62	6.61	0.54	7.22	0.64
April	7.27	0.58	7.34	0.61	7.23	0.59	6.48	0.61	6.79	0.51	7.30	0.60
May	7.31	0.54	7.39	0.62	7.26	0.58	6.43	0.61	6.84	0.53	7.36	0.62
June	5.60	0.55	5.75	0.56	5.70	0.52	5.77	0.57	5.06	0.50	5.80	0.57
July	5.16	0.50	5.39	0.54	5.35	0.49	5.30	0.52	4.51	0.45	5.50	0.53
August	4.69	0.46	5.09	0.49	5.01	0.49	4.86	0.47	4.26	0.42	5.24	0.51

September	5.19	0.51	5.54	0.55	5.64	0.49	5.46	0.54	5.48	0.46	5.78	0.57
October	5.81	0.56	5.91	0.57	6.01	0.56	5.92	0.57	5.48	0.56	5.81	0.58
November	6.04	0.68	6.03	0.64	6.05	0.59	6.01	0.61	5.97	0.58	6.00	0.65
December	5.82	0.58	5.75	0.57	5.75	0.56	5.76	0.56	5.83	0.55	5.72	0.54
Annual Average Irradiation per Day (kWh/m^2)	6.16	0.57	6.30	0.59	6.27	0.57	6.02	0.59	5.75	0.52	6.35	0.60

Source: [NASA/NIMET]

I_h= Daily Average Monthly Global Solar Irradiance on Horizontal Surface,

K_T= Clearness Sky Index

Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe are all regions with great solar energy potential. Adamawa sees favorable conditions with monthly average irradiation ranging from 5.75 kWh/m² to 7.31 kWh/m², offering a robust basis for solar energy projects. Bauchi also has high Clearness Sky Index, suggesting optimum conditions for solar energy generation. Borno experiences abundant sunshine throughout the year, with a high Clearness Sky Index, indicating great potential for solar energy expansion. Gombe, with an annual average irradiation of 6.02 kWh/m², also indicates promise for solar energy growth. Taraba has a lower yearly average irradiance but yet provides a nuanced view on solar potential. Yobe, with an annual average irradiation of 6.35 kWh/m², likewise has high sunshine, offering favorable conditions for solar energy installations. These favorable solar conditions enable policymakers and stakeholders make educated decisions about solar infrastructure investments and sustainable energy planning.

Table 4. 3: Power Obtainable using 1% of Available Land Mass from Each of the States in the Study Locations

State	Annual Average Irradiation per Day (kWh/m^2/day)	Energy Obtainable per Square Meter per Year Considering Performance Factor (kWh/m^2)	1% of Land Mass Used (m^2 X 10^3)	Power Obtainable when 1% of Land Mass is used (MW)
Adamawa	**6.16**	**449.68**	**369,170.00**	**45,481.74**
Bauchi	**6.30**	**459.90**	**646,050.00**	**81,402.30**
Borno	**6.27**	**457.71**	**711,300.00**	**89,197.02**
Gombe	**6.02**	**439.46**	**187,680.00**	**22,596.67**
Taraba	**5.75**	**419.75**	**559,200.00**	**64,308.00**
Yobe	**6.35**	**463.55**	**422,700.00**	**53,682.90**
Total			**2,896,100.00**	**356,668.64**

Source: Researcher

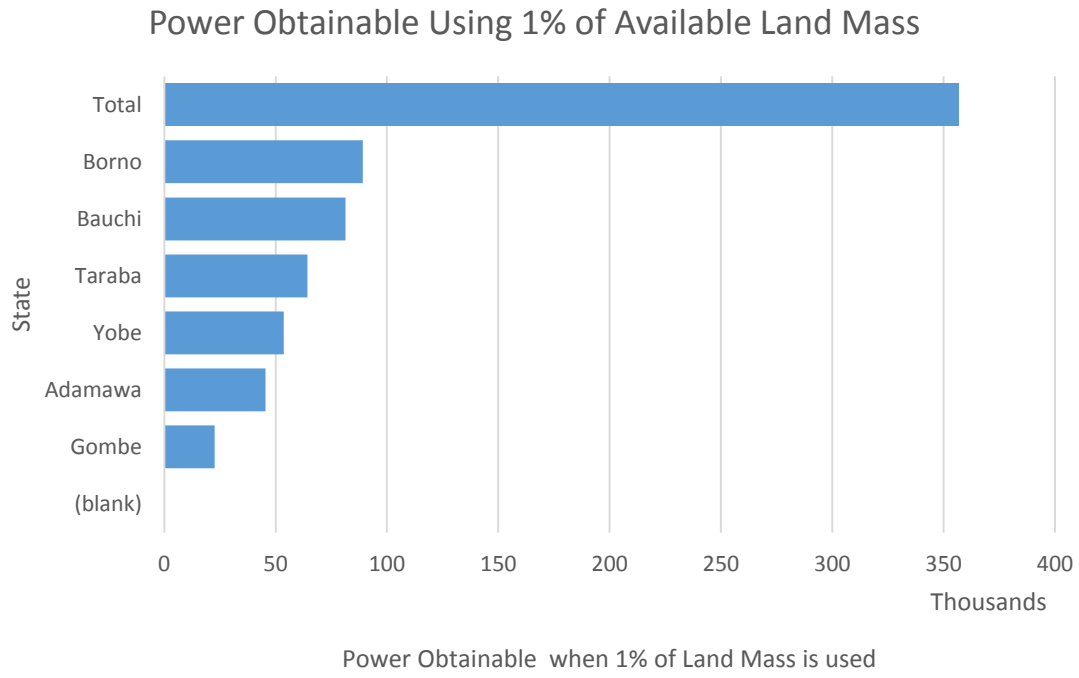


Figure 4. 1:Power Obtainable Using 1% of the Available Land Mass

Adamawa, Bauchi, Borno, Gombe, and Yobe are among the six North-Eastern states in Nigeria that have demonstrated substantial potential for solar energy development. Adamawa has a high yearly average irradiation of 6.16 kWh/m², indicating a steady platform for solar energy generation. Bauchi, on the other hand, has an annual average irradiation of 6.30 kWh/m² and a considerable power achievable of 81,402.30 MW. These findings emphasize Bauchi's smart use of land for solar operations, harmonizing with environmental protection measures. Borno, with an annual average irradiation of 6.27 kWh/m², has an expected power achievable of 89,197.02 MW. Gombe, with an annual average irradiation of 6.02 kWh/m², offers great potential for solar energy growth, with a power achievable of 22,596.67 MW. Taraba, with a lower annual average irradiation of 5.75 kWh/m², also indicates considerable potential for solar energy growth. Yobe, with an annual average irradiation of 6.35 kWh/m², offers considerable potential for solar energy growth. These findings can help policymakers and stakeholders make educated decisions for sustainable energy development in the region.

Summary of Findings

The North-Eastern area of Nigeria offers tremendous potential for solar energy generation, despite constraints such as high initial investment costs, inadequate public

awareness, and insurgency. The North-East's energy environment, characterized by previous reliance on conventional sources and warfare, requires particular efforts to harness solar energy. Off-grid efforts, particularly in the face of violence, offer a localized and off-grid approach to enhance electricity supply in rural areas. The North-East's solar potential is vital in tackling socio-economic challenges, notably restricted access to dependable power. Policymakers may leverage this potential through investment incentives, new legislation, and enhanced public knowledge. The optimization of land utilization, allowing just 1% for solar systems, indicates dedication to environmental conservation and economic prosperity. With strategic planning, investment, and community engagement, the North-East may become a beacon of sustainable development in Nigeria.

Policy Recommendations

Solar energy is a viable answer for the North-East, with both local and international corporations investing in solar panels. Policymakers should stimulate investment in solar panels and batteries, establishing a favorable atmosphere for investors. Public awareness efforts may enhance understanding of solar energy's benefits, while security measures are vital for the region's energy infrastructure. Optimizing land utilization for solar energy systems and restricting consumption to 1% can assure environmental conservation while supporting economic growth through renewable energy programs.

Future Research Directions

The North-Eastern portion of Nigeria is adopting solar energy, despite the hurdles created by the insurgency. The study underscores the necessity for community engagement in solar energy projects, boosting project performance and sustainability. It also underscores the necessity for developing technology to lower initial investment costs and enhance efficiency. The report underlines the need for smart policies and investments to properly exploit the promise of solar energy.

References:

R. B. Mshelia, "Assessment of Renewable Energy Potentials of The Northeast Geopolitical Region of Nigeria Potentials for Energy Generation and Greenhouse Gases Emission Reduction from Municipal Solid Waste in Yola Metropolis View project Higher Education Campus Greenhouse Gas Emissions View project." [Online]. Available: https://www.researchgate.net/publication/351946112

I. G. Friday, B. C. Udochukwu, T. Igbawua, T. Alaxander, and O. J. Ndubuisi, "Assessment of Global Solar Radiation at Selected Points in Nigeria Using Artificial Neural Network Model (ANNM)," *Int. J. Environ. Clim. Chang.*, pp. 376–390, Jul. 2019, doi: 10.9734/ijecc/2019/v9i730123.

K. O. Obi and A. A. Uzodigwe, "Assessing the Optimal Electricity Supply in Nigeria," *J. Bus. Stud. Q.*, vol. 7, no. 3, 2016.

N. V. Emodi and S. D. Yusuf, "Improving Electricity Access in Nigeria: Obstacles and the Way Forward," *Int. J. Energy Econ. Policy*, vol. 5, no. 1, pp. 335–351, 2015, [Online]. Available:

www.econjournals.com
Federal Ministry of Power, "NATIONAL RENEWABLE ENERGY AND ENERGY APPROVED BY FEC FOR Ministry of Power Federal Republic of Nigeria," 2015, [Online]. Available: http://admin.theiguides.org/Media/Documents/NREEE POLICY 2015- FEC APPROVED COPY.pdf
A. E. Agwu, D. Raheem, M. C. Muteba, and S. N. Foster, "Micro-hydropower systems for smallholder farmers in rural communities of Taraba state, Nigeria: Socioeconomic assessment of needs and perceptions (Part I)," *Energy Nexus*, vol. 10, no. April, p. 100191, 2023, doi: 10.1016/j.nexus.2023.100191.
D. Diji, "A Critical Review of the Nigerian Energy Scenario," *IOSR J. Electr. Electron. Eng.*, vol. 5, no. 3, pp. 55–67, 2013, doi: 10.9790/1676-535567.
I. D. Ibrahim *et al.*, "A review on Africa energy supply through renewable energy production: Nigeria, Cameroon, Ghana and South Africa as a case study," *Energy Strateg. Rev.*, vol. 38, no. October, p. 100740, 2021, doi: 10.1016/j.esr.2021.100740.
F. I. Abam, B. N. Nwankwojike, O. S. Ohunakin, and S. A. Ojomu, "Energy resource structure and on-going sustainable development policy in Nigeria: A review," *Int. J. Energy Environ. Eng.*, vol. 5, no. 2–3, pp. 1–16, Jul. 2014, doi: 10.1007/s40095-014-0102-8.
A. B. Owolabi, B. E. K. Nsafon, and J. S. Huh, "Validating the techno-economic and environmental sustainability of solar PV technology in Nigeria using RETScreen Experts to assess its viability," *Sustain. Energy Technol. Assessments*, vol. 36, no. September, p. 100542, 2019, doi: 10.1016/j.seta.2019.100542.
U. S. Akpan, S. R. Isihak, and Y.-O. N. Udoakah, "Electricity Access in Nigeria: Viability of Off-Grid Photovoltaic System."
M. C. . Njoku, I. F. . Isong, A. N. . Njoku, E. A. . Kennet, and T. Neebani, "Solar Radiation Evaluation in North-East Geo-Political Zone of Nigeria," *Iconic Res. Eng. Journals*, vol. 5, no. February, pp. 140–151, 2022.
N. Bashir, B. Modu, and J. Bahru, "Techno-Economic Analysis of Off-grid Renewable Energy Systems for Rural Electrification in Northeastern Nigeria Lightning Detection System View project Transformer insulation View project Techno-Economic Analysis of Off-grid Renewable Energy Systems for Rural Electrification in North-eastern Nigeria," 2018. [Online]. Available: https://www.researchgate.net/publication/328661183
O. M. Aderoju, G. A. Dias, and Z. Echakraoui, "Assessment of Renewable Energy Sources & Municipal Solid Waste for Sustainable Power Generation in Nigeria," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Dec. 2017. doi: 10.1088/1755-1315/95/4/042043.
H. O. Njoku, "Solar PV Potential in Nigeria SOLAR PHOTOVOLTAIC POTENTIAL IN NIGERIA 1," no. June, 2014, doi: 10.1061/(ASCE)EY.1943-7897.0000145.
K. Owebor, E. O. Diemuodeke, T. A. Briggs, and M. Imran, "Power Situation and renewable energy potentials in Nigeria – A case for integrated multi-generation technology," *Renew. Energy*, vol. 177, pp. 773–796, 2021, doi: 10.1016/j.renene.2021.06.017.
T. A. Adagunodo, A. A. Adeniji, A. M. Ajao, and N. O. Anie, "Alternative to excessive consumption of fossil fuels in Nigeria: A case of solar energy system," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1197, no. 1, 2023, doi: 10.1088/1755-1315/1197/1/012001.
S. C. Nwokolo, J. C. Ogbulezie, and O. J. Ushie, "A multi-model ensemble-based CMIP6 assessment of future solar radiation and PV potential under various climate warming scenarios," *Optik (Stuttg).*, vol. 285, no. July 2021, p. 170956, 2023, doi: 10.1016/j.ijleo.2023.170956.
C. O. Okoye, O. Taylan, and D. K. Baker, "Solar energy potentials in strategically located cities in Nigeria: Review, resource assessment and PV system design," *Renew. Sustain. Energy Rev.*, vol. 55, pp. 550–566, 2016, doi: 10.1016/j.rser.2015.10.154.
O. A. Odetoye, P. K. Olulope, O. M. Olanrewaju, A. O. Alimi, and O. G. Igbinosa, "Multi-year techno-economic assessment of proposed zero-emission hybrid community microgrid in Nigeria using HOMER," *Heliyon*, vol. 9, no. 9, p. e19189, 2023, doi: 10.1016/j.heliyon.2023.e19189.
U. Akpan, "Technology Options for Increasing Electricity Access in Areas with Low Electricity Access

Rate in Nigeria (Interim Report).” [Online]. Available: http://www.nigeriapowerreform.org/
Y. N. Chanchangi, F. Adu, A. Ghosh, S. Sundaram, and T. K. Mallick, *Nigeria’s energy review: Focusing on solar energy potential and penetration*, no. 0123456789. Springer Netherlands, 2022. doi: 10.1007/s10668-022-02308-4.
A. A. Osinowo, E. C. Okogbue, S. B. Ogungbenro, and O. Fashanu, “Analysis of Global Solar Irradiance over Climatic Zones in Nigeria for Solar Energy Applications,” *J. Sol. Energy*, vol. 2015, pp. 1–9, 2015, doi: 10.1155/2015/819307.
D. O. Akinyele, R. K. Rayudu, and N. K. C. Nair, “Life cycle impact assessment of photovoltaic power generation from crystalline silicon-based solar modules in Nigeria,” *Renew. Energy*, vol. 101, pp. 537–549, 2017, doi: 10.1016/j.renene.2016.09.017.
Q. M. Ajao, R. J. Haddad, and A. El-Shahat, “Comparative Analysis of Residential Solar Farm with Energy Storage between the USA and Nigeria,” *Conf. Proc. - IEEE SOUTHEASTCON*, vol. 2019-April, 2019, doi: 10.1109/SoutheastCon42311.2019.9020420.
S. C. Nwokolo, S. O. Amadi, A. U. Obiwulu, J. C. Ogbulezie, and E. E. Eyibio, “Prediction of global solar radiation potential for sustainable and cleaner energy generation using improved Angstrom-Prescott and Gumbel probabilistic models,” *Clean. Eng. Technol.*, vol. 6, no. May 2021, p. 100416, 2022, doi: 10.1016/j.clet.2022.100416.
A. TANSU, A. T. OGUNGBEMİ, and F. TANSU HOCANIN, “The challenges and serviceability of solar power: suggestion on solving the Nigeria energy crisis,” *Int. J. Energy Stud.*, vol. 7, no. 2, pp. 127–141, 2022, doi: 10.58559/ijes.1177950.
A. Babajide and M. C. Brito, “Solar PV systems to eliminate or reduce the use of diesel generators at no additional cost: A case study of Lagos, Nigeria,” *Renew. Energy*, vol. 172, pp. 209–218, 2021, doi: 10.1016/j.renene.2021.02.088.
O. R. O, O. A. S. O, A. T. R, A. A. Yusuff, and T. C. Mosetlhe, “An assessment of proposed grid integrated solar photovoltaic in different locations of Nigeria: Technical and economic perspective,” *Clean. Eng. Technol.*, vol. 4, p. 100149, 2021, doi: 10.1016/j.clet.2021.100149.
E. P. Agbo, C. O. Edet, T. O. Magu, A. O. Njok, C. M. Ekpo, and H. Louis, “Solar energy: A panacea for the electricity generation crisis in Nigeria,” *Heliyon*, vol. 7, no. 5, p. e07016, 2021, doi: 10.1016/j.heliyon.2021.e07016.
N. M. Linah, O. C. Meludu, J. Aidan, and M. E. Kundwal, “Performance of 20 Watts Polycrystalline Silicon Solar Module under Yola Climate, North-East Nigeria,” *Eur. J. Eng. Res. Sci.*, vol. 4, no. 4, pp. 70–73, Apr. 2019, doi: 10.24018/ejers.2019.4.4.1248.
Z. Chongkon, “An Overview of Renewable Energy Development in Nigeria over the Years : Challenges and Control Measures ZAMAN , Chongkon Haruna M . Eng . Department of Electrical and Electronics Engineering , Faculty of Engineering and Engineering Technology Abubakar Taf,” no. April, 2023, doi: 10.14293/PR2199.000082.v1.
“Solar Radiation and Daylight Models.”
M. Suri *et al.*, “Online data and tools for estimation of solar electricity in Africa : the PVGIS approach To cite this version : HAL Id : hal-00465775,” no. May 2014, 2010.