International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 20, Issue 12 (December, 2024), PP 38-45

A Hybrid Renewable Energy Systems for Sustainable Electrification: A Case Study of Nuhu Bamalli Polytechnic Zaria-Nigeria

Mahmud Mustapha[1], Ibrahim Bashir Shehu[2] and Danasabe Gambo[3]
Electrical/Electronic Engineering Technology Department, Nuhu Bamalli Polytechnic Zaria

Abstract
This research investigates the optimization of hybrid renewable energy systems for sustainable electrification, focusing on the case study of Nuhu Bamalli Polytechnic Library in Zaria, Nigeria. The study explores the significant potential of wind and solar photovoltaic (PV) energy in the Zaria region and compares various configurations, including Grid/Wind, Solar PV/Wind/Battery/Inverter/Grid, and Solar PV/Inverter/Battery/Grid hybrid renewable energy systems. The findings reveal that electrifying the polytechnic library using an on-grid hybrid renewable energy system is more cost-effective than relying solely on centralized grid supply. The hybrid Grid/Wind configuration is identified as the most promising option, demonstrating the least levelized cost of energy (LCOE) at N8.86/kWh, the lowest net present cost (NPC) at N19.7 million, and high energy production per year. The study underscores the potential of on-grid wind energy systems and hybrid renewable energy configurations in providing sustainable energy solutions for educational institutions. This research contributes to the understanding of renewable energy feasibility in Nigeria and suggests avenues for future studies in optimizing hybrid configurations and incorporating diverse renewable energy sources.
Keywords: *Renewable Energy, Hybrid System, Grid-connected, Solar and Wind*

Date of Submission: 27-11-2024 Date of Acceptance: 05-12-2024

I. Introduction

Renewable energy sources are gaining increasing attention as viable alternatives to conventional power generation, offering sustainable solutions to growing energy demands. In the context of educational institutions, such as Nuhu Bamalli Polytechnic in Zaria, Nigeria, the exploration of renewable energy options becomes imperative for fostering energy sustainability and reducing environmental impact. This study delves into the optimization of hybrid renewable energy systems to meet the energy needs of the polytechnic library, focusing on the integration of wind and solar photovoltaic (PV) technologies.

The global shift towards renewable energy aligns with Nigeria's commitment to diversify its energy mix and harness its abundant renewable resources. As established by Ajayi (2010), Nigeria possesses substantial wind energy potential that remains largely untapped. Additionally, solar irradiance data from the Global Solar Atlas indicates favorable conditions in the study area (Global Solar Atlas, 2022). The quest for sustainable energy solutions is particularly relevant for educational institutions, where energy demands are essential for academic activities, research, and overall campus functionality.

In the Nigerian context, previous studies have explored the feasibility of various renewable energy sources (Adesina *et al.,* 2023; Mohammed *et al.,* 2013). However, there is a need for site-specific investigations to determine the most efficient and cost-effective configurations tailored to the unique energy requirements of institutions like Nuhu Bamalli Polytechnic. The present research aims to fill this gap by conducting a comprehensive analysis of hybrid renewable energy systems, emphasizing the on-grid hybridization of wind and solar PV technologies.

The introduction of renewable energy solutions for educational institutions is strategic, not only for reducing reliance on conventional grid power but also for fostering a culture of sustainability among students and faculty. This paper unfolds the findings of a meticulous study that evaluates the potential of on-grid hybrid configurations, considering factors such as levelized cost of energy (LCOE), net present cost (NPC), and annual energy production. The research contributes valuable insights to the broader discourse on renewable energy adoption in Nigeria and offers recommendations for optimizing hybrid systems in similar contexts.

II. Literature Review

Renewable energy has emerged as a pivotal focus in addressing the energy needs of diverse sectors, including educational institutions. This literature review provides an overview of relevant studies, examining the potential of wind and solar photovoltaic (PV) technologies, and explores the significance of hybrid configurations in the context of Nuhu Bamalli Polytechnic, Zaria.

Ajayi (2010) emphasizes the underexplored wind energy potential in Nigeria, presenting a case for its viability as a sustainable energy source. This aligns with the findings of this study, which identifies significant wind energy potential in the research location (Zaria). As demonstrated by the research, incorporating wind energy into hybrid configurations contributes to optimal energy production.

Solar energy, characterized by abundant sunlight, is a prominent renewable resource in Nigeria (Mohammed *et al.*, 2013). The Global Solar Atlas (2022) provides insights into solar irradiance data, affirming the suitability of the study area for solar PV integration. The report echoes the importance of harnessing solar energy, particularly in hybrid systems, to enhance overall energy production.

Previous researches (Adesina *et al*., 2023; Falama *et al.*, 2023) has delved into comparative analyses of various hybrid configurations. Adesina et al. (2023) focus on off-grid solar-powered systems, while Falama *et al.* (2023) conduct a multi-criteria assessment of on/off-grid connected renewable energy systems. These studies provide a backdrop for the current research, emphasizing the need for comprehensive evaluations to identify the most suitable hybrid configurations.

Chandel *et al.* (2014) and Ahmed *et al.* (2023) contribute to the understanding of the techno-economic aspects of solar photovoltaic systems. Their analyses of solar photovoltaic power plants and economic feasibility studies align with the economic considerations presented in the current study. The high net present cost associated with solar PV configurations, as revealed in this research, underscores the economic challenges of relying solely on solar energy.

Konstantinidis and Botsaris (2016) provide insights into the current status, obstacles, and trends in wind energy systems. Their work aligns with the recommendation for incorporating wind energy into the hybrid configuration, as identified in the present study. The comparative advantage of the hybrid grid/wind configuration supports the argument for integrating wind turbines into the energy mix.

This literature review establishes a foundation for understanding the renewable energy landscape in Nigeria, emphasizing the potential of wind and solar PV technologies. The current study builds upon these insights by offering a site-specific analysis of hybrid renewable energy systems for Nuhu Bamalli Polytechnic, providing valuable recommendations for future research and implementation.

III. Materials and Method

This research employs a comprehensive and systematic methodology to evaluate the feasibility and optimization of hybrid renewable energy configurations for the energy needs of Nuhu Bamalli Polytechnic, Zaria. The methodology encompasses data collection, simulation, and analysis, drawing on Homer Pro software. The stepwise approach is designed to ensure accuracy, reliability, and relevance in addressing the research objectives. The methodology can be itemized as:

- ✓ Literature review
- ✓ Data/information collection from the Nigeria Meteorological Agency (NIMET), similar websites and load profile of the site.
- ✓ System design, in-depth analysis and simulation using Homer Pro renewable energy software.
- ✓ Discussion and analysis of the result.

3.1 Data Collection:

Data such as solar irradiation and other renewable energy resources were obtained from Global Solar Atlas and National Aeronautics and Space Administration (NASA) websites while information regarding load consumption of the library were obtained from power ratings of the equipment, energy usage and duration of use by different users of the facility. These data were used for load profiling and component sizing of equipment used in the study.

Table 3.1: Site Information for Nuhu Bamalli Polytechnic Library (Global Solar Atlas, 2022)

S/N	Description	Quantity
1	Specific Photovoltaic Power Output (PVOUT)	4.674 kWh/kWp/day
2	Direct Normal Irradiance (DNI)	4.095 kWh/m^2/day
3	Global Horizontal Irradiance (GHI)	5.830 kWh/m^2/day
4	Diffuse Horizontal Irradiance (DHI)	2.816 kWh/m^2/day
5	Global Tilted Irradiation at Optimum Angle (GTI opta)	6.001 kWh/m^2/day
6	Optimum Tilt of PV Module (OPTA)	16/180 ◦
7	Air Temperature (TEMP)	25.2 ◦C
8	Terrain Elevation (ELE)	649 m

9	Coordinate	11.037333°N, 007.673944°E

Table 3.1 presents solar energy resource for the study site. The global tilted irradiation for the site is about 6 kWh/m^2/day at 16/180◦ which demonstrated a good potential for solar power plant. The global position of the site as well as its terrain elevation were 11.037333°N, 007.673944°E and 649 m respectively.

Table 3.2: Average monthly data of wind speed, solar irradiation and temperature (NASA, 2023)

Month	Wind speed (m/s)	Irradiation (kWh/m^2)	Temperature (°C)
January	6.89	5.520	19.40
February	6.70	6.170	22.83
March	5.88	6.490	26.26
April	5.01	6.560	28.25
May	4.66	6.260	27.42
June	4.65	5.860	25.75
July	4.27	5.310	24.44
August	3.74	4.940	23.82
September	3.44	5.420	24.23
October	3.76	5.730	24.26
November	5.11	5.710	22.83
December	6.89	5.710	19.40

The mean wind speed, solar irradiation and ambient temperature for the site as obtained online from the NASA website is presented in Table 3.2 while the estimated energy demand is presented in Table 3.3 based on load type, number of operational hours in a day and the average energy demand in kWh/day.

Table 3.3: Estimated Energy Demand for the Library

Load type	Power (kw)	Duration of use (h)	Energy (kWh/day)
Lights	1.60	14	22.40
Fans	6.60	10	66.00
Air conditioners	14.25	7	99.75
Televisions	0.50	8	4.00
Security lights	0.33	12	3.96
Tech. Services, printing & bindery	1.60	8	12.80
Miscellaneous	1.28	14	17.92
	26.16		**226.83**

Table 3.3 shows that energy used per day for all categories of load is 226.83 kWh/day and the average energy per year is estimated to be 82,792.95 kWh/year. The daily power and energy demand obtained were used in sizing system components. An hourly load profile for a single day serves as an input for simulation with HOMER Pro software.

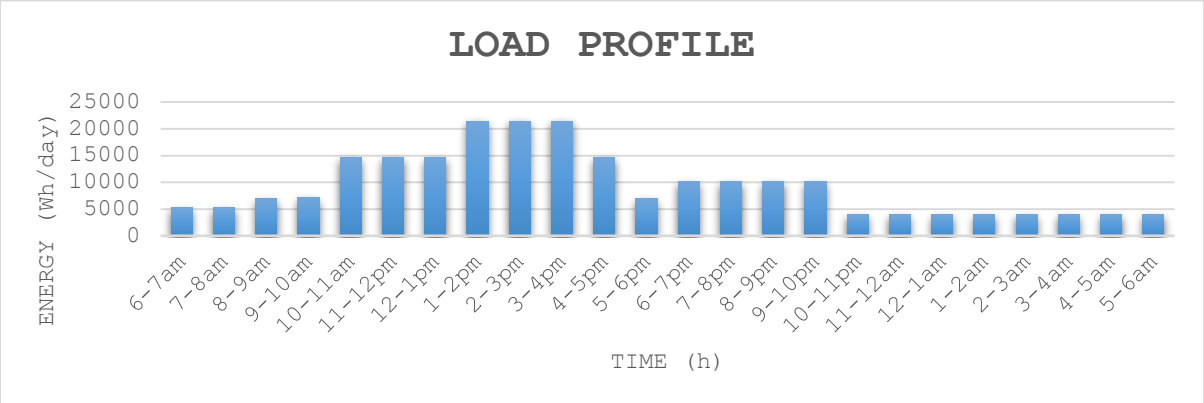

Figure 3.1: Daily Load Profile of the Library

Figure 3.1 presents a daily load profile for January developed by Homer Pro software using 24-hour energy consumption of the library. The average energy demand is 226.83kWh/day while the peak load is 36.51kW.

Table 3.4: Components Costs and quantities

Component Description	***Capacity***	***Quantity***	***Unit Price***	***Price (NGN)***
Fronius Symo 24.0 Inverter	30 KVA	2	2,250,000.00	5,500,000.00
LONGi LR6-72 Solar Panel	380 W	134	114,402.99	15,330,000.00
BAE SECURA SOLAR 12V Battery	200 AH	46	170,000.00	7,820,000.00
Felicity MPPT Charge Controller	100 A	10	150,000.00	1,500,000.00
Eocycle E020 Wind Turbine	20 kW	12	891,000.00	10,692,000.00
Cable and Accesories			Lot	500,000.00
Miscellaneous			Lot	400,000.00
Total Cost				**41,742,000.00**

IV. Results and Discussions

The research findings provide a comprehensive assessment of three different configurations for meeting the energy demands of Nuhu Bamalli Polytechnic. The configurations include Grid/Wind, Solar PV/Wind/Battery/Inverter/Grid and Solar PV/Inverter/Battery/Grid. The evaluation criteria include energy production, operating costs, levelized cost of energy (LCOE), and net present cost (NPC).

Energy Production

The energy production per year for each configuration was analyzed, revealing that the Grid/Wind configuration exhibited the most responsible energy production option, approximately 99.58% of the Solar PV/Wind/Battery/Inverter/Grid configuration in addition to having the least LCOE.

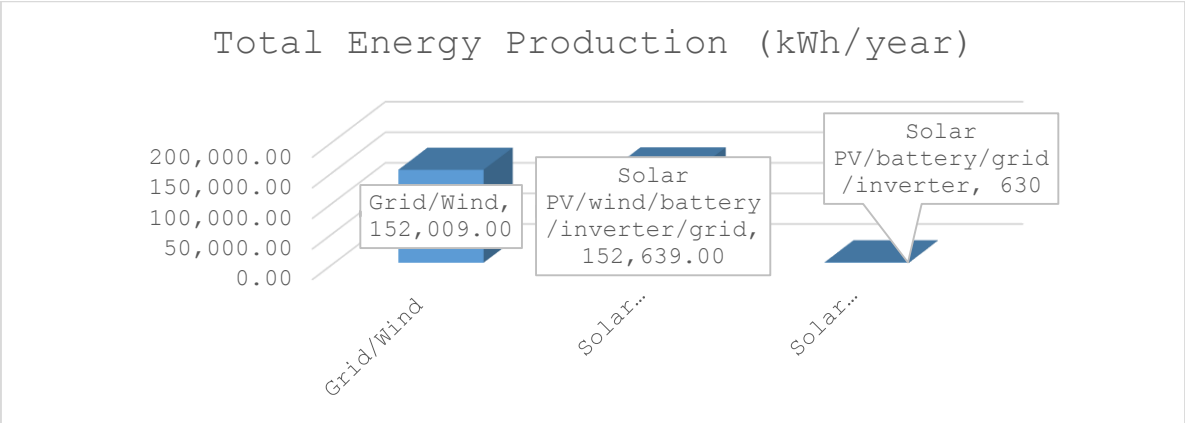

Figure 4.1: Energy Production of Different Configurations

Operating Costs

The operating costs of the three configurations were compared, and Figure 4.2 illustrates the yearly operating costs. The Grid/Wind configuration emerged as the most cost-effective option, with the lowest operating cost per year among all configurations. It was followed by the Solar PV/Wind/Battery/Inverter/Grid configuration.

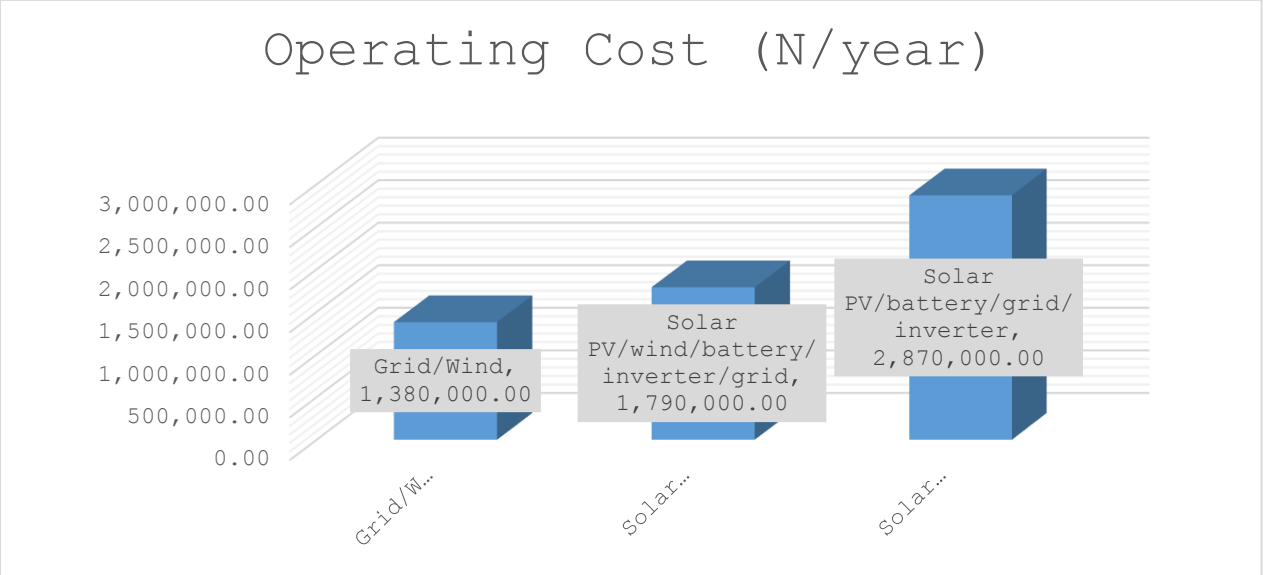

Figure 4.2: Operating Costs of Different Configurations

The above figure shows that the *Grid/Wind* configuration exhibited the option with least operating cost.

Levelized Cost of Energy (LCOE)

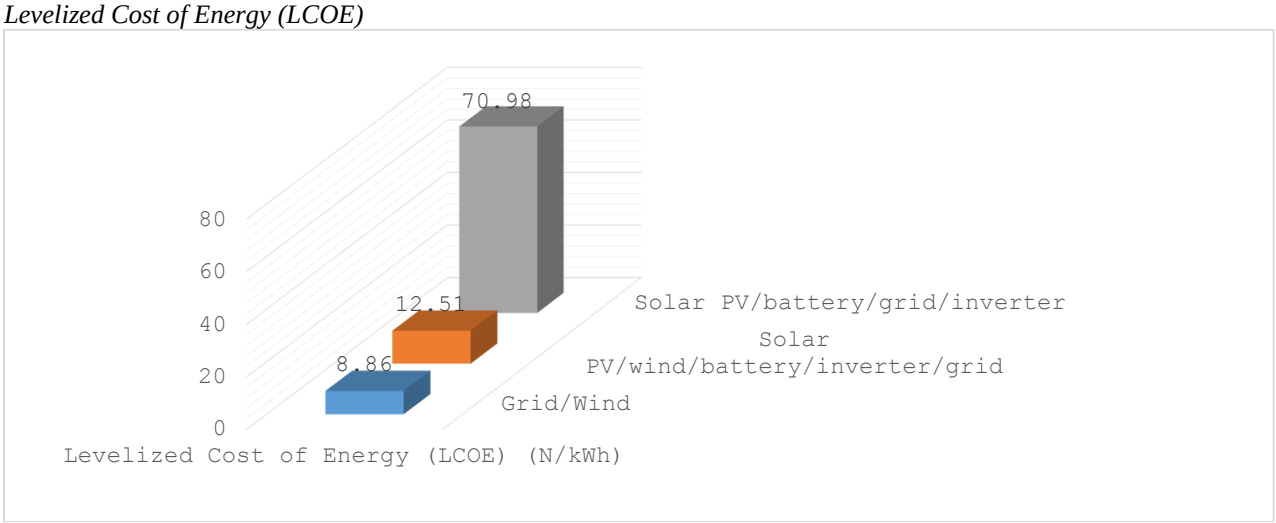

Figure 4.3: Levelized Cost of Energy for Different Configurations

Figure 4.3 presents the LCOE for each configuration, representing the cost per unit of energy. The Grid/Wind configuration demonstrated the lowest LCOE at N8.86/kWh, establishing itself as the most economically favorable option. The Solar PV/Wind/Battery/Inverter/Grid configuration followed with LCOEs of N12.51/kWh.

Net Present Cost (NPC)

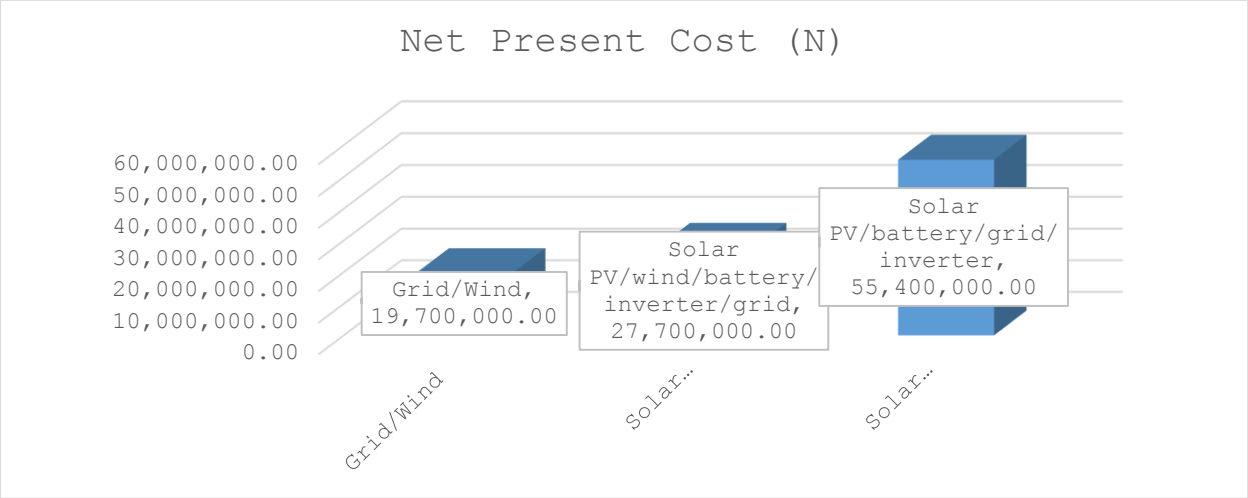

Figure 4.4: Net Present Cost for Different Configurations

The net present cost for each configuration is highlighted in Figure 4.4. The Grid/Wind configuration exhibited the lowest NPC at N19.7 million, indicating its economic viability. In contrast, the Solar PV/Inverter/Battery/Grid configuration showed the highest NPC at N55.4 million.

These findings collectively identify the Grid/Wind configuration as the most promising option, offering high energy production, low operating costs, favorable LCOE, and a cost-effective NPC. The results underscore the economic and technical advantages of hybrid renewable energy systems over conventional approaches, providing valuable insights for sustainable energy planning.

V. Conclusion and Recommendations

In conclusion, this research conducted an in-depth analysis of various energy configurations to meet the electricity demand of Nuhu Bamalli Polytechnic library, with a focus on energy production, operating costs, levelized cost of energy (LCOE), and net present cost (NPC). The major findings and conclusions drawn from this study are summarized below:

1. Energy Potential: The study affirmed the substantial potential for wind and solar photovoltaic energy in the research location, Zaria. This establishes a foundation for harnessing renewable energy sources to address the facility's power needs.

2. Cost-Effectiveness of On-Grid Hybrid Renewable Energy: It was determined that electrifying the Polytechnic library using on-grid hybrid renewable energy is a more cost-effective approach than relying solely on centralized grid supply. This insight can guide future energy infrastructure decisions for similar institutions.

3. Optimal Configurations: Among the three configurations evaluated, the hybrid grid/wind configuration emerged as the most favorable for electricity supply to the library. This configuration exhibited the least LCOE at N8.86/kWh, the lowest NPC at N19.7 million, and high energy production per year, positioning it as the optimal choice.

4. Comparative Analysis: Comparative analyses revealed that on-grid solar PV configurations are the least economically attractive options due to their elevated net present costs and higher operating costs.

5. Validation of Hybrid Renewable Energy Systems: The research findings underscore the effectiveness of on-grid hybrid systems, which proved to be economically viable and capable of meeting the energy needs of the library facility.

5.1 Recommendations for Future Studies

To further enhance the understanding of renewable energy solutions, future research should consider incorporating multiple sources such as biomass, small hydro, and solar thermal. Additionally, extending the study to larger facilities or communities could provide more comprehensive insights into the scalability and applicability of the identified configurations.

References

[1]. Acharya, P. S., & Aithal, S. P. (2020). A Comparative Study of MPPT and PWM Solar Charge Controllers and their Integrated System. Journal of Physics: Conference Series, 1712(2020), 012023.

[2]. Adesina, L. M., Ogumbiyi, O., & Makinde, K. (2023). Design, Implementation and Performance Analysis of an Off-Grid Solar Powered System for a Nigerian Household. Methods X, 10(2023), 102247.

[3]. Ahmed, G. A., et al. (2023). Analysis of the PV system Sizing and Economic Feasibility Study in a Grid-Connected PV System. Case Studies in Thermal Engineering, 45(2023), 102903.

[4]. Ajayi, O. O. (2010). The Potential for Wind Energy in Nigeria. Journal of Wind Engineering, 4(3), 303-312.

[5]. Amina, I. S., Nafi'u, T., & Bilyaminu, A. (2012). Wind Power: An Untapped Renewable Energy Resource in Nigeria. International Journal of Scientific & Engineering Research, 3(9), 1-4.

[6]. Amole, A. O., et al. (2021). Comparative Analysis of Techno-Environmental Design for Wind and Solar Energy for Sustainable Telecommunications Systems in Different regions of Nigeria. International Journal of Renewable energy Research, 11(4), 1776-1792.

[7]. Ayodele, E. B., & Dickson, E. (2017). Estimating the Solar Home Sizing for Rural Residential Apartments using a Panel Tilt angle of 82 Degrees: Ilorin Kwara State as Case Study. Journal of Electrical and Computer Engineering, 1(3), 90-96.

[8]. Benjamin, T. A., & Gideon, A. D. (2014). Renewable Energy Resources in Benue state, Nigeria: Estimation and Mapping of Solar Energy Potentials. International Journal of Current Engineering and Technology, 4(3).

[9]. Chandel, M., Agrawal, G. D., Mathur, S., & Mathur, A. (2014). Techno-economic analysis of solar photovoltaic power plant for garment zone of Jaipur city. Case Studies in Thermal Engineering, 2 1–7. doi: 10.1016/j.csite.2013.10.002.

[10]. Eldis A. (2020). An Overview of Kaduna state Economy 2002 – 2008. www. Eldis.org. Retrieved 15th July 2022.

[11]. Esan, A. B., & Egbune, D. (2017). Estimating the Solar Home System Sizing for Rural Residential Apartments Using a Panel Tilt Angle of 82 Degrees: Ilorin, Kwara State as Case Study. Electrical and Computer Engineering Journal, 1(3), 90-96.

[12]. Falama, R. Z., et al. (2023). A Comparative Analysis Based Multi-Criteria Assessment of On/Off Grid Connected Renewable Energy Systems: A Case Study. Energies, 16(1540), 1-25.

[13]. Global Solar Atlas. (2022). Nuhu Bamalli Map Data Site Information. https://globalsolaratlas.info/map?c=11.037333,7.673944,11&s=11.037333,7.673944&m=site.

[14]. Homer Pro. (2022). Hybrid Optimization of Multiple Energy Resources. www.homerenergy.com.

[15]. Iyabo, A. I. (2020). Assessing the Effect of Rural Electrification on Household Welfare in Nigeria. Journal of Infrastructure Development, 12(1), 7-24.

[16]. Jung, C., & Schindler, D. (2019). The Role of Air Density in Wind Energy Assessment: A Case Study from Germany. Energy, 171(2019), 385-392.

[17]. Kibara, S., Murage, D. K., Musao, P., & Saolo, M. J. (2020). Comparative Analysis of Implementation of Solar PV Systems using the Advanced SPECA Modelling Tool and Homer Software: Kenyan Scenario. High Tech and Innovation Journal, 1(1), 8-20.

[18]. Kevin, Noor V. P., Jufri F. H., Naradhipa A.M., & Utomo A.R. (2020). Optimization and Comparative Analysis of a Stand-alone Hybrid Model of PV, Wind Turbine and Natural Gas Generator in Remote Area: A Case Study of Belu. 2nd International Conference on Green Energy and Environment (ICoGEE 2020).

[19]. Konstantinidis, E. I., & Botsaris, P. N. (2016). Wind Turbines: Current Status, Obstacles, Trends and Technologies. 20th Innovative Manufacturing Engineering and Energy Conference (IManEE 2016).

[20]. Kusakana, K., Munda, J. L., & Jimoh, A. A. (2009). Feasibility study of a hybrid PV-Micro Hydro system for rural electrification. IEEE AFRICON 2009*.

[21]. Leonics Support. (2015). How to Design Solar PV System. https://www.leonics.com/support/article2_12j/articles2_12j_en.php.

[22]. Marwan, M. M., & Imad, H. I. (2006). Techno-economic feasibility of energy supply of remote villages in Palestine by PV-systems, diesel generators and electric grid. Journal of Renewable and Sustainable Energy, 10, 128-138.

[23]. Mohammed, Q. T. (2013). Performance analysis of wind turbine systems under different parameters effect. International Journal of Energy and Environmental, 3(6), 895 - 904.

[24]. Mohammed, Y. S., Mustafa, M. W., Bashir, N., & Mokhtar, A. S. (2013). Renewable Energy Resources for Distributed Power Generation in Nigeria: A Review of the Potential. Renewable and Sustainable Energy Reviews, 22, 257-268.

[25]. Nigeria Meteorological Agency, Abuja-Nigeria. (2006). www.nimetng.org.

[26]. Nada, Q. M. (2019). Comparative Analysis between solar and Wind Turbine Energy Sources in IoT based on Economical and Efficiency Considerations. International Conference on Control Systems and Computer Science (CSCS 2019).

[27]. National Aeronautics and Space Administration. (2023). Solar Irradiance. https://www.nasa.gov/.

[28]. Nigerian Electricity Regulatory Commission (NERC). (2016). NERC Mini-Grid Regulation. https://nerc.gov.ng/.

[29]. Ogbonnaya, I., Okoro, E., Chikuni, K., & Govender, P. (2007). Prospects of Wind Energy In Nigeria. Journal of Wind Engineering, 34(3), 320-322.

[30]. Oladigbolu, J. O., Al-Turki, Y. A., & Olatomiwa, L. (2021). Comparative study and sensitivity Analysis of a standalone hybrid energy system for electrification of rural healthcare facility in Nigeria. Alexandria Engineering Journal, 60(6), 5547–5565. doi: 10.1016/j.aej.2021.04.042.

[31]. Oparaku, O. U. (2003). Rural area power supply in Nigeria: A cost comparison of the photovoltaic, diesel/gasoline generator and grid utility options. Journal of Renewable Energy, 28, 2089-2098.

[32]. Osinowo, A. A., Okogbue, E. C., Ogungbenro, S. B., & Fashanu, O. (2015). Analysis of Global Solar Irradiance over Climatic Zones in Nigeria for Solar Energy Applications. Journal of Solar Energy, 2015, 1–9. doi: 10.1155/2015/819307.

[33]. Pelz, S., Narge, C., Clara, N., & Philipp, B. (2023). Electricity Supply and Use among rural and Peri- urban Households and Small Firms in Nigeria. Nature Scientific data, 10(273), 1-7.

[34]. Pradeep, A., & Tiwari, H. P. (2011). Electrification by Mini Hybrid PV-Solar/Wind Energy System for Rural, Remote and Hilly/Trible Areas in Rajasthan (India). IEEE.

[35]. Rizwan, M. S. S., et al. (2017). A Review Paper for Electricity Generation from Solar Energy. International Journal for Research in Applied Science and Engineering Technology, 5(IX), 1884-1889.

[36]. Sambo, A. S. (2009). Strategic Developments in Renewable Energy in Nigeria. International Association of Energy Economics Third Quarter 2009, 15-19.

[37]. Sunday, O. O. (2012). Energy and Sustainable Development in Nigeria: The Way forward. Energy, Sustainability and society Open Journal, 2(15).

[38]. Tanvir, M. M., et al. (2019). Estimation of Number of Turbines, Power Rating, Cost, Modelling of the Wind Turbine Blade & Prospects of Wind Energy in the Coastal Region of Bangladesh. Global Scientific Journal, 7(12), 291-302.

[39]. Tomy, A., Wing, W. A. R., & Devara, K. (2019). Solar Charge Controller with Maximum Power Point Tracking for Low Power solar Applications. International Journal of Photoenergy, 2(19), 1-11.
[40]. Wang, H. X., et al. (2017). Optimum Inverter Sizing of Grid-Connected Photovoltaic Systems based on Energetic and Economic considerations. Renewable Energy. doi:10.1016/2017.11.063.
[41]. World Bank. (2000). Energy services for the world's Poor. Washington DC: The World Bank.