OFF-GRID PLANTS IN NIGERIA: INDICATING LOCATION, CAPACITY, PERFORMANCEAND PRESENT STATUS

Abstract:
The power sector in Nigeria still struggles with significant electricity challenges resulting from the unavailability of power supply and unreliability of the conventional national grid. It has been reported that both urban and rural areas suffer the impact of power shortages and frequent blackouts. The unreliability of power supply in Nigeria has been identified as a significant problem affecting educational institutions in terms of productive learning, student residency and institutional operations, and also the overall operation of healthcare facilities as it limits access to quality healthcare services. The study examines the presence and potential of off-grid power solutions in Nigeria which present a more reliable approach to supplying electricity to users, as a deliberate response to the multiple and complex challenges in the Nigerian power systems to identify the present location, installed capacity, operational performance, and current status of off-grid power plants in Nigeria. The Geographic Information System and statistical approaches were employed. It was discovered that off-grid solutions are beginning to spread across the country on different scales. However, most rural areas in Nigeria still do not have access to electricity supply. The study encourages decentralized power generation in the country and emphasizes the need for the federal government through the Rural Electrification Agency (REA) to consider investing in off-grid solutions, particularly in the rural areas for socio-economic benefits.

KEYWORDS:*Off-grid power, Nigeria, energy access, data analysis, installed capacity, performance,Geographic Information System (GIS).*

I. INTRODUCTION

In Nigeria, the national grid plays a principal role in the power sector. However, its unreliability and incapacityto meet the ever-increasing demand for electricity has always resulted in frequent blackouts, which hurts both rural and urban regions. The unreliability of the on-gridpower system has motivated the birth of an off-grid alternative approach to accessing electricity to communities.

Off-grid power plants in Nigeria play a crucial role in addressing the country's energy challenges by providing decentralized and reliable electricity to remote areas. As Nigeria strives for sustainable development,off-grid solutionshave become progressively important and a strategic response to multifaceted challenges and the pursuit of overarching goals.

The term "off-grid" in its simplest form refers to energy systems that are not connected to the central grid infrastructure. These systems can include standalone solar power systems, wind turbines, microgrids, and other localised power generation and distribution solutions.

In Nigeria, the exploration of off-grid power plants has become increasingly essential in addressing energy challenges. As the country seeks sustainable solutions, off-grid systems offer a promising avenue for decentralized and reliable electricity access, particularly in remote areas where traditional grid infrastructure is limited.

The off-grid power solution aims to enhance access to reliable electricity, especially in remote regions where traditional grid penetration is challenging. This initiative is motivated by a set of objectives encompassing economic development, social empowerment, and environmental sustainability. However, this also comes with obstaclessuch as financial barriers, infrastructural constrictions, and the like.

For many years, Nigeria has been faced with the continuous struggle for power supply to her citizens from the national grid which is an On-grid power system. Even thoughseveral homes, companies, and other commercial establishments are connected to the national grid, there are still the majority of people who do not have access to the national grid because of geographical locations or lack of finance to service their electricity bills.

Among others, Nigeria faces several challenges with its on-grid power plants, contributing to issues in the country's overall power sector;some of which include:

- Inadequate and unsatisfactory power generation creates gaps between electricity demand and supplywith the effect in regular power shortages.
- Unreliable power supply resulting in frequent outages and fluctuations with significant negative effects on businesses and household operations and the impacton economic productivity.

- Lack of network Infrastructure which refers to the transmission and distribution networks that are incapableof meetingthe growing energy demand and of course,causingtransmission losses, inadequacies, and contributing to a less reliable electricity supply.
- The interruption of natural gas supply for gas-poweredplants in Nigeria as a result of pipeline vandalization has negatively affected the on-grid power generation and also the stability of the grid.
- Electricity theft and non-payment of bills have been identified as major challenges that affect the financial state of the distribution companies and also impact the company revenue. Revenue losses make it difficult for utilities to invest in improvements, affecting the quality and reliability of power supply.
- Poor maintenance culture contributes to the deterioration of power infrastructure and reduces efficiency and the lifespan of power plants. This also contributes greatly to the frequency of downtime and of course, higher maintenance costs, and reduces the reliability of the power generation system.
- Inconsistent guidelines, regulatory uncertainties, and political interference contribute to a challenging business environment for power sector stakeholders. Lack of long-term planning, regulatory stability, and clear policies hinder private sector investment and overall sector development.

Off-grid power solutions, including decentralized renewables, microgrids, energy storage, and community engagement, offer viable alternatives to address these challenges. Executing off-grid solutions can meaningfully contribute to closing the energy access gap, especially in remote and underserved areas. As Nigeria engages in a diversified and robust energy landscape, a mixture of on-grid and off-grid solutions can guarantee a more reliable, sustainable, and all-encompassing power supply for Nigeria's energy needs.

Off-grid power solutions play a vital role in this endeavour as they address energy needs in remote environments, reduce the environmental impact that comes with on-grid power generation, encourage economic growth, promote educational opportunities, and improve healthcare services.

II. LITERATURE REVIEW

2.1 The Lack of Power Supply

The foundation of any societal development and improved quality of life of any nation depends largely on the availability of and accessibility of electricity supply. As of 2014, the International Energy Agency Report indicated that more than 1.3 billion people globally still lacked consistent access to electricity.

The majority of these people live in rural areas. The inaccessibility to electricity especially the rural area has posed some challenges in realizing the Millennium Development Goals (MDGs).

According to Emodi (2015), access to reliable and affordable electricity supply is anindispensablenecessity for economic growth, improved living standards, and overall development in any country. Nigeria, as the most populous nation in Africa, has long struggled with insufficient power supply from the national grid.

Even though a significant portion of Nigeria's population is connected to the national utility grid, there are still residents, particularly in rural areas, who face challenges in establishing connections due to financial constraints and/or environmental factors. As a result, Emodi(2015)reported that formost residences,electricity is generatedfrom gasoline or diesel-powered generators, which can be noisy and have the effect of increasing greenhouse gas emissions which hurts the environment. Besides other environmental problems associated with the use of petrol and diesel generators, it is quite expensive to run them. With the emergence of off-grid system solutions, many residents in Nigeria are making attempts and adopt the off-grid system owing to the economic implication of running generators.

2.2 Demand and Supply of Electricity in Nigeria

According to a report released by the UN Department of Economic and Social Affairs contained in Vanguard Nigeria Newspaper (2017), it has been predicted that Nigeria will be the world’s third most populous country by 2050. Statistics from experts show that by 2040, Nigeria's

population will have multiplied by 4% without proportional employment and social amenities to sustain it.

According to the Vanguard Newspaper (2019) report, the federal government of Nigeria under the administration of His Excellency Mohammed Buhari (GCFR) records shows that power generation increased to 1,811.3 Megawatts, in January 2019 while the transmission company of Nigeria (TCN) transmitted 127,157.7 Megawatts as compared to 125,346.4 Megawatts in December 2018. However, this was considered insufficient to supply the energy demand of a developingnation like Nigeria. This shows that there is an extremely poor electricity supply in Nigeria which has resulted in a wide demand/supply gap.

Adesola (2008) in a lecture on data capture processing, 2006 population and housing census of Nigeria in Tanzania, reported that unreliability and interruption of power was a key challenge encountered in the 2006 census. Similarly, the Central Bank of Nigeria's 4th quarter statistical bulletin (2012) reported that insufficient power supply is a major limitation to business growth and development in Nigeria. Business owners as a result of this deficiency generate their power to run their businesses which has now resulted ina high cost of living.

In a publication made by Doris (2023), it states that Nigeria is the most populous country in Africa. It highlights that Nigeria's population increased to over two hundred million in the year 2020. With this amount, a high volume of electricity generation is required to meet the electricity demand of the individual Nigerians. In the same year, however, power generated amounted to about 35.7 thousand gigawatt hours. Having generatedthis power, it is considered insufficient in comparison to the level of electricity demand, which surpassed 29 terawatt hours in the same year. It was recommended to encourage more electricity generation investment in the country to close out the gap in the demand-supply of electricity in the country.

2.3 Access to Electricity

Good infrastructural services, especially electricity, are a prerequisite to the rapid and sustainable socio-economic growth of any country. However inadequate and unreliable access to electricity services has been a regular feature in the Nigerian power sector (Amadi, 2015). Not everyone in Nigeria canacquire electricity for use. Doris (2020),reported that only about 55% of Nigerianscould access electricity. It was reported in the Vanguard Nigeria Newspaper (2019),

that 30% of the population had electricity and the absence of electricity was more prevalent in rural areas while 90% was recorded in the urban population.

Furthermore, in the same year, it was reported that the northeast and northwest zonesrecorded high levels of lack of electricity.Besides, it was noted that as of 2022, the electricity demand in Nigeria has risen to over 32 terawatt hours. Following the Statista's prediction, the household, and industries' average electric power consumption per capita will riseon an annual basis. The report added that by 2023, consumption per Nigerian household will rise to approximately 165 kilowatt hours (kWh) andgrowup to 166 kilowatt hours by 2025.

2.4 Solar PV Hybrid Energy System

Studies have revealed that the subject of generating renewable off-grid power in rural regions is no longer new as Okoye (2018) carried out a study on the economicfeasibility of solar PV systems for rural electrification in sub-Sahara Africa, comparing the cost of electricity from solar photovoltaic (PV) to a standalone diesel generator in a rural region in Nigeria. The author found a difference of USD 0.22/kWh in the use of the two energy technologies and therefore considered a solar mini-grid a more economical approach for power generation. A feasibility study has also been carried out by Olatomiwa et al. (2015), by evaluating the economic implications of executing a Solar PV/diesel/battery hybrid energy system in the six geopolitical zones of Nigeria. In this research a diesel generator was considered as a backup source of energy and was meant to run for a short duration. A group of researchers have explored the possibility of running a completely renewable energy-based mini solar grid solution. A case study was that of Bertheau (2020), investigating the use of solar/wind/battery systems for the electrification of an island in the Philippines. In the same vein, Krishan and Suhag (2019) evaluated the use of three hybrid arrangements for a community in India with a deprived source of electricity and concluded that a wind/solar/battery system was the most cost-effective choice for the region. Nevertheless, the Arthurs underscored the location-dependent nature of wind technology in mini-grid systems applications.

It is obvious that the centralized power generation and distribution system has not been adequate in meeting the growing energy demands of the nation's burgeoning population and it is therefore the aim of this review study to comprehensively analyze off-grid power plants in Nigeria, breaking down their presence by geopolitical locations, and assessing the installed capacities and

operational status and performances in each state and recommend more availability and accessibility of off-grid power supply to the rural and underserved regions.

III. MATERIALS AND METHODS

This section details the approach employed in our study by providing a comprehensive account of our investigational approach. We seek to provide valuable insights into the practical challenges and opportunities of off-grid power systems and also serves as a foundation for future advancements in the field.

3.1 Data Collection

The data for this analysis was collected through a combination of primary and secondary sources. Primary data was obtained throughinterviews with industry experts. Secondary data was sourced from a review of official reports from relevant government agencies, energy reports, and academic literature. The study covers a specified timeframe and includes a representative sample of off-grid plants across different regions in Nigeria. The key variables considered include plant location, installed capacity, operational efficiency, and current status.

3.2 Data Types

The collected data comprises both quantitative and qualitative data. Quantitative data includes numerical values such as installed capacity. Qualitative data encompasses insights from interviews and on-site observations, providing a nuanced understanding of the plants' operational challenges and successes.

3.3 Data Analysis

The quantitative data are subjected to statistical analysis using tools such as descriptive statistics. Geographic Information System (GIS) mapping techniques are employed to visualize the spatial distribution of off-grid plants. Qualitative data undergoes thematic analysis to identify recurring patterns, challenges, and success factors.

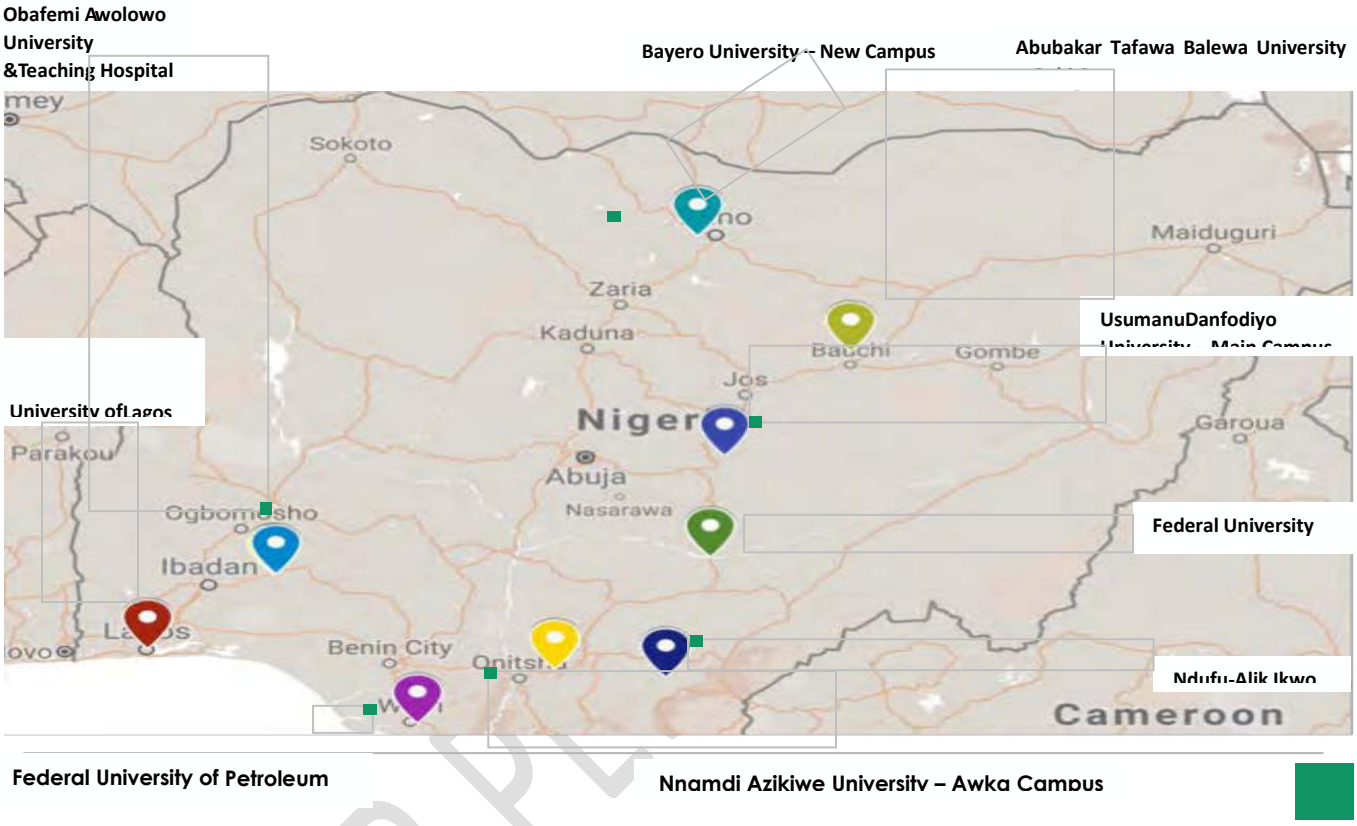
Table 1: Renewable and Data-Driven ElectrificationSolutions in Nigeria

	North-Central	North-West	North-East	South-West	South - East	South - South
2020						
GRID	32	18	28	23	16	26
SOLAR STREET LIGHT(SSL)	6	2	3	1	2	4
SOLAR MINI GRID (SMG)	8	10	6	7	6	5
SOLAR HOME SYSTEMS (SHS)	60	73	61	36	47	20
TOTAL	**106**	**103**	**98**	**67**	**71**	**55**
2021						
GRID	46	32	24	24	38	28
SOLAR STREET LIGHT(SSL)	1	1	-	1	2	2
SOLAR MINI GRID (SMG)	1	1	-	-	5	1
SOLAR HOME SYSTEMS (SHS)	31	51	27	24	31	32
TOTAL	**79**	**85**	**51**	**59**	**76**	**63**
2022						
GRID	37	25	32	13	28	16
SOLAR STREET LIGHT(SSL)	53	63	48	56	33	45
SOLAR MINI GRID (SMG)	4	4	1	2	7	9
SOLAR HOME SYSTEMS (SHS)	4	4	1	1	2	2
TOTAL	**98**	**96**	**82**	**72**	**70**	**72**

Source: Rural Electrification Agency Impact Report

RESULTS AND DISCUSSION

The data gathered and analyzed are hereby presented in this section. They include both quantitative and qualitative data.



Pic1: Spatial distribution of off-grid plants

4.1 Some Off-Grid Plants in Nigeria

The data gathered and analyzed shows that off-grid power plants are spread across the country, serving both urban and rural areas on different scales.

For this study, the authors focus on some selected off-grid plants across Nigeria for quick identification and analysis.

1. **Off-Grid Plant at the Federal University of Agriculture, Makurdi**

   An off-grid power plant has been identified on the campus of the Federal University of Agriculture, Makurdi in Benue State, in the North Central part of Nigeria. The plant runs on a Solar PV-hybrid technology and has a capacity of 8.25MW. The plant is currently active and performing optimally.The plant was constructed by the Rural Electrification Agency (REA) under the Energizing Education Program (EEP) of the federal government in July 2018 and was completed in August 2020 and commissioned in October 2020.

2. **Off-Grid Plantat the Bayero University in Kano**

   Located on the campus of Bayero University in Kano, Kano State, in the Northern part of Nigeria is a Solar PV-hybrid off-grid plant with a capacity of 7.1MW. The plant consist of 10,680 solar panels installed on approximately 2 hectares of land space. The plant is actively running and performing efficiently.The project which lasted from February 2018 to September 2019 was executed by the Rural Electrification Agency (REA) under the Energizing Education Program (EEP) of the federal government.

3. **Off-Grid Plant at Alex Ekwueme Federal University**

   The off-grid power plant at Alex Ekwueme Federal University located in Ndufu Alike-Ikwo, Ebonyi state, in the Southeastern region of Nigeria signifies sustainable energy solution in the institution as it aims to enhance energy availability and reliability and redirect attention from the national grid. It has a capacity of 2.8 megawatts (MW), with solar PV component consisting of 3,500 solar panels. The plant is actively in operation with high efficiency in performance. The project was executed by the Rural Electrification Agency (REA) on behalf of the federal government.

4. **Off-Grid Plant at Usman Dam in Bwari, Abuja**

   The water treatment plant rated 1.52MW employs an inventive off-grid approach, designed to operate off the conventional power grid. The facility derives its source from renewable energy for its operations, ensuring sustainable practices and resilience.

   The off-grid solar PV plant is strategically located at the Usman Dam in Bwari, Abuja. Where limited access to the main power grid has been identified as a challenge. The plant is presently up and performing efficiently.

5. **Off-Grid Plant at Nigeria Breweries (NB) Plc**

The off-grid solar PV plant at Nigeria Breweries (NB) Plc is located in the city of Ibadan, Oyo State, in the Southwestern part of Nigeria serving as a major facility for sustainable energy and operational independence. The plant has a capacity of 0.663MW with 1,680 solar panels. The plant construction which started in March 2019 became actively operational in November 2020 and it is performing excellently.

6. **Off-Grid Plant at Federal University of Petroleum, Effurun**

The 1.35MW Solar Hybrid off-grid power plant located at the Federal University of Petroleum, Effurun (FUPRE), Delta State; serves as a decentralized energy source in supporting the university's day-to-day operations. The plant is still actively playing essential roles in meeting the electricity need of the facilities within the university.

7. **Off-Grid Plant at Nnamdi Azikiwe University**

Nnamdi Azikiwe University off-grid plant is a 2.5MW solar PV power plant, well located within the Nnamdi Azikiwe University campus in Anambra state, Nigeria. The project is designed to enhance energy generation in the institution. The project commenced in 2018 and was completed in 2019 and is currently active and performing well up to date.

8. **Off-Grid Plant at UsumanuDanfodiyo University**

The project was designed to effectively serve the staff members and students of UsumanuDanfodiyo University in Sokoto state with safe, clean, and reliable energy. The 2.0MW Solar (PV) hybrid is currently and adequately powering the University campus and the library including streetlights on the campus.

Some off-grid power plants in Nigeria has been identified in the studyand the summary of the plants showing their geographical location, installed capacity, operational performance and current status are tabulated in table 2.

Table 2. Some Off-Grid Plants In Nigeria

S/N	OFF-GRID PLANT	LOCATION	CAPACITY (MW)	PERFORMANCE	PRESENT STATUS
1	Nigeria Breweries Plc	Ibadan, Oyo State	0.663	Optimal	Active
2	Alex Ekwueme Federal University	Ndufu Alike-Ikwo, Ebonyi State	2.8	Optimal	Active

3	Usman Dam Water Treatment Plant	Bwari, Abuja.	1.52	Optimal	Active
4	UsmanuDanfodiyo University	Sokoto, Sokoto State	2	Optimal	Active
5	Nnamdi Azikiwe University	Awka, Anambra State	2.5	Optimal	Active
6	Bayero University, Kano (Buk)	Kano, Kano State	7.1	Optimal	Active
7	Federal University of Agriculture, Makurdi (Funai)	FUNAI, Benue State	8.25	Optimal	Active
8	Federal University Of Petroleum, Effurun	Effurun, Delta State	1.35	Optimal	Active

4.2 The Presence of Solar Photovoltaic(PV) Solutions in Nigeria

Solar photovoltaic (PV) technology is progressively taking hold of the energy market and gaining popularity in Nigeria as a sustainable energy solution. Considering the solar PV technology deriving its energy from the sunlight, it is evidence that it has the advantages of minimizing greenhouse gas emissions and less dependency on fossil fuels. The technology is particularly beneficial in remote areas as Solar PV requires less maintenance, hence reduced cost. While reliance on the national grid has proven to be unreliable, the use of solar PV solutions ensures energy security.

The study has gathered that the drastic growth in solar PV installation in Nigeria is a response to the demand for clean energy solutions.

Data from the installation of different Solar (PV) solutions has been taken as cited in table 1 and analyzed for three years across the six geo-political locations in Nigeria and are presented in figures 1, 2 and 3.

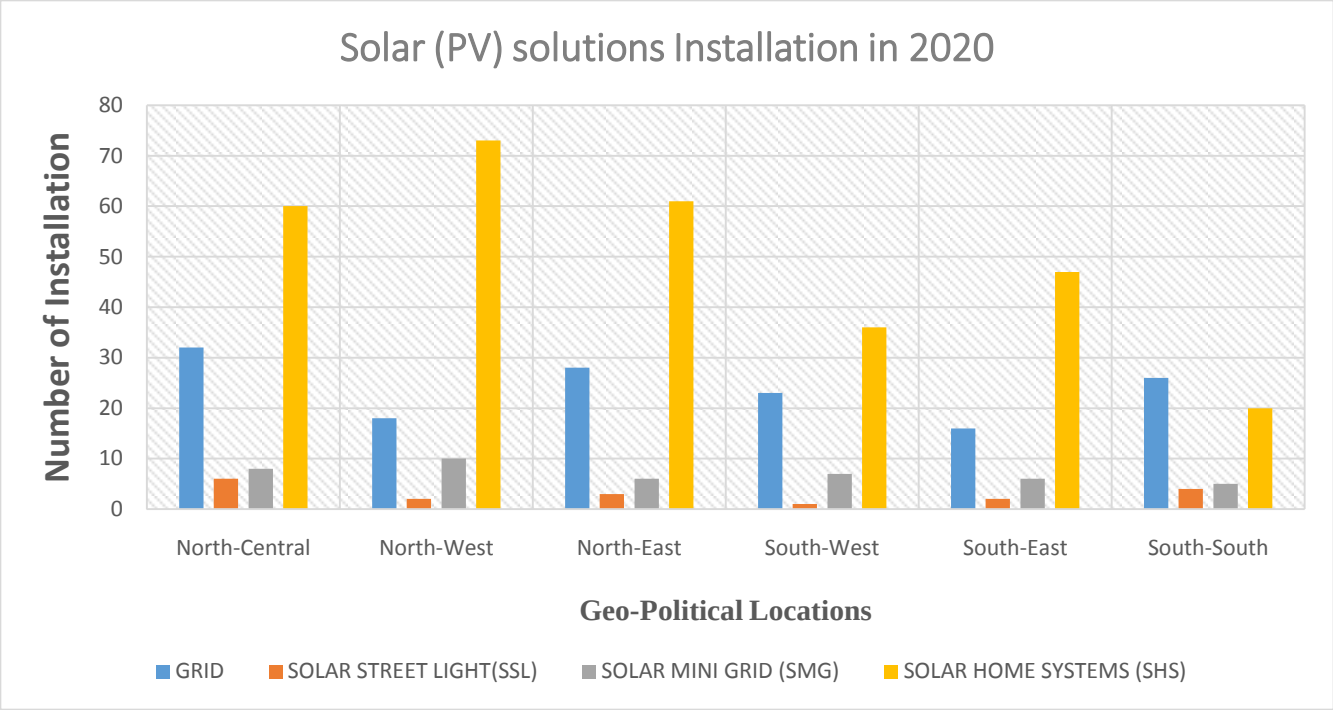


Figure 1: Solar (PV) Solutions Installation in 2020

The assessment of off-grid initiatives across different geo-political locations in Nigeria indicates a booming Grid business in the country and it uncovers thousands of opportunities for potential off-grid projects.

The report presented in Figure 1 shows that the off-grid plant is present in all geo-political locations with the highest number situated in the North-Central and the least in South-East locations respectively.

While Solar Street Lights and Solar Mini Grid are relatively distributed across the different locations, they appear to be low in their numbers; hence, there is need for more investment. The solar home systems appear to be in abundance.

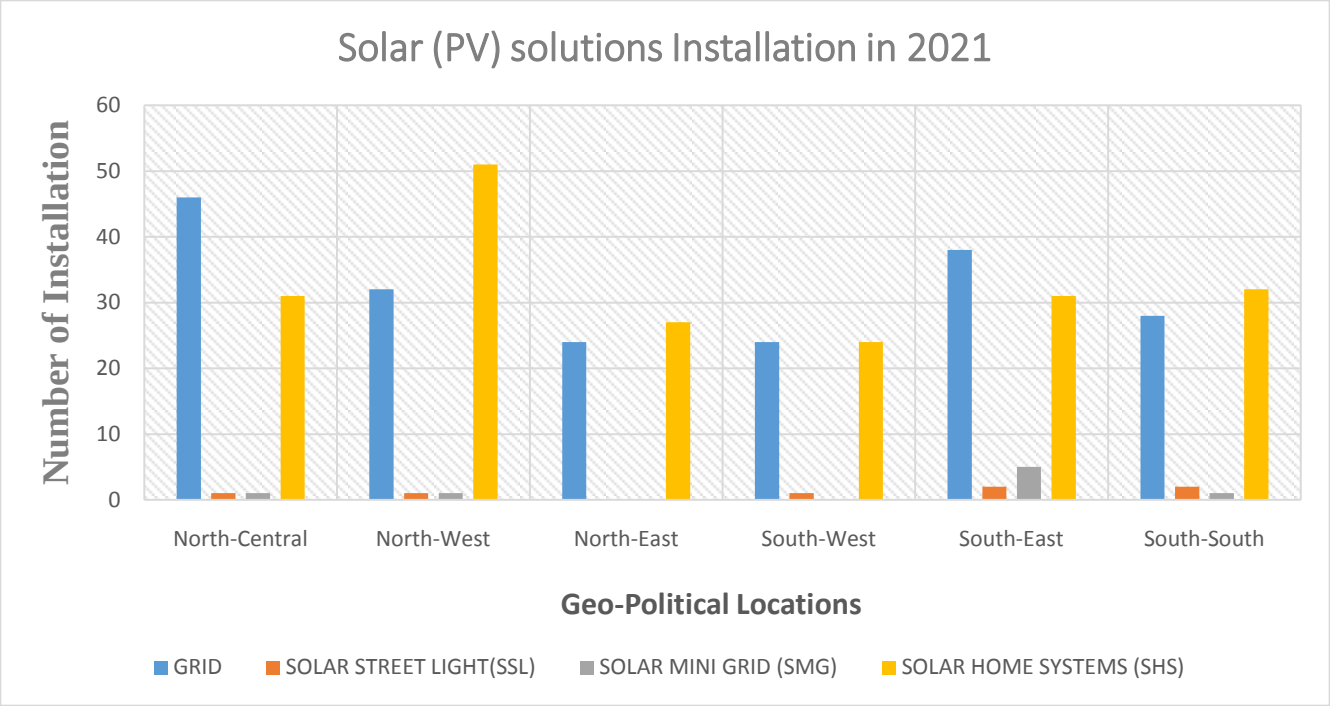


Figure 2: Solar (PV) solutions Installation in 2021.

In 2021, considering the same locations, there appear to be an appreciable improvement in the number of the Grid plants compared to that of 2020. It records more in the North-Central and least in North-East and South-East. In the same vein, like that of 2020, the Solar Street Light and Solar Mini Gridreported to be very low in this year, even lower than the previous year. Again, attention is needed for investment in these areas.

The presence of the Solar Home Systems in these locations signifies a good number of users. This can also be attributed to its low economic viability. It can be afforded at a very low price.

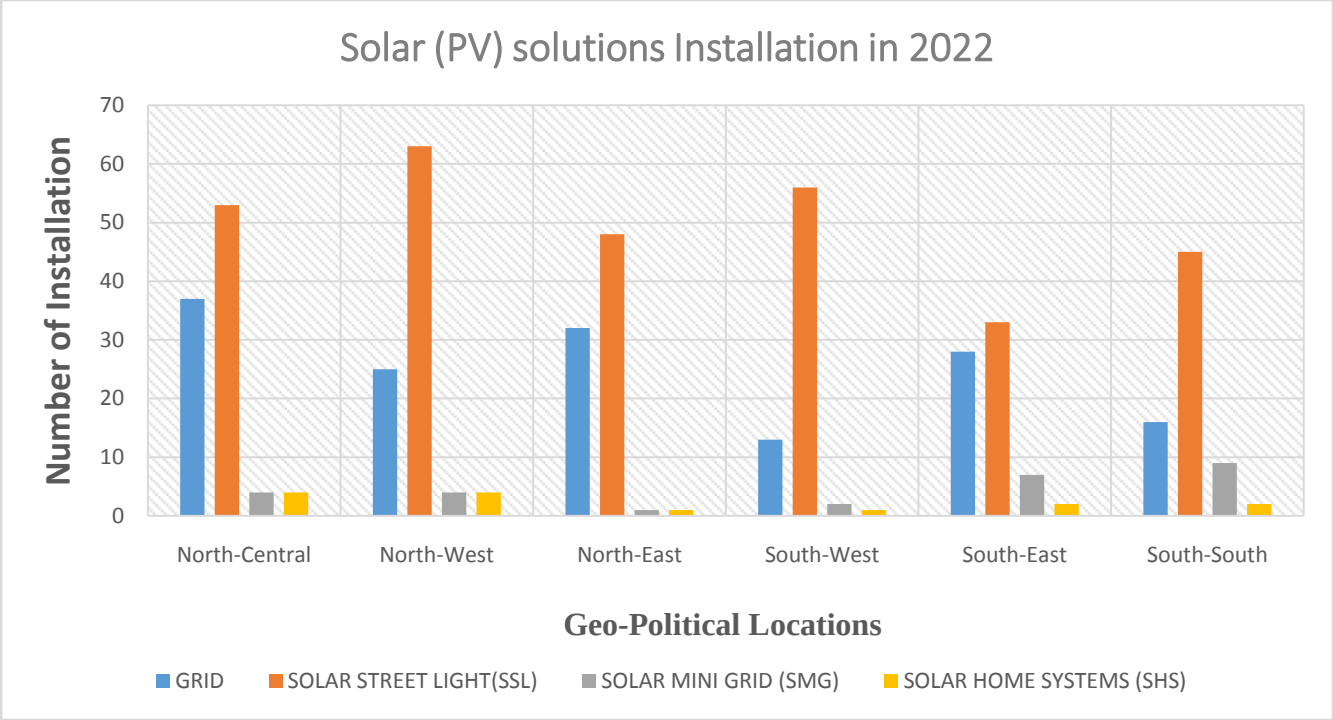


Figure 3: Solar (PV) solutions Installation in 2022.

In 2022, asubstantial increase in the number of Solar Street Light plants was recorded. It indicates how widespread the Solar Street Light has gone in Nigeria.However, the count of grid plants in these regions during the same period was comparatively lower. Solar Street Light plant records 49% more than the solar grid.

In this year, the solar mini grid and solar home systems appear to be low across the regions. From the statistics of 2022, it therefore calls for more investment in grid plants so as to reach especially the remote and underserved regions.

The examination of off-grid power plants in Nigeria revealed valuable insights pertaining to their geographical dispersion, installed capacity, operational efficacy, and present status. By identifying these specific details, the research aimed to offer a thorough portrayal of the off-grid power landscape in the country.

CONCLUSION

Off-grid power plants in Nigeria has been identified. The assessment involves examining their location, capacity, operational performance, and current status. It's imperative to know that the

advancement in off-grid plants and renewable energy initiatives is liable to change. This could be influenced by factors such as changes in government policies, technological innovations, and global energy trends.

Given the plans made by Nigeria in increasing generation capacity in the coming years and also considering the limitation in accessing electricity in rural areas. The study emphasizes the need for significant investment in off-grid generation and actively seeking financial support from the Development Finance Institutions, World Bank, and NGOs to expedite electrification plans and achieve improved electricity in the country. In achieving the desired increase in generation, Nigeria requires both on-grid and off-grid power projects. By combining both, it promises the potential to accelerate the achievement of full electrification in the country, consequently providing substantial economic development in Nigeria, as power is a catalyst for economic growth.

Furthermore, the study emphasized the decentralization of off-grid solutions among federal, state, and local governments. This distributed approach would speed up the execution of off-grid projects and the long-term plan actualization. The variation of off-grid power plants and other renewable solutions across diverse regions has the potential to exert political influence on a nation like Nigeria by shaping perceptions of governance, dedication to sustainability, and resilience to disasters. Economically, it can contribute to achieving energy independence, fostering rural development, generating employment opportunities, and enhancing access to essential services. The specific impacts will depend on the scale, technology, and policies surrounding the implementation of off-grid power solutions in each locality. The research contributes to knowledge by furnishing a thorough and current comprehension of Nigeria's off-grid power sector. It extends the existing body of literature by presenting precise details on the geographical distribution, capacities, operational efficiency, and current status of off-grid power plants. This information holds significance not only for Nigeria but also for other regions or nations considering similar off-grid power projects. The study on off-grid power plants in Nigeria is instrumental in addressing crucial knowledge voids, delivering practical insights, and acting as a valuable reference for stakeholders engaged in energy planning, policy formulation, and investment choices.

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