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An Empirical Study of Solar PV Adoption and Power Generation in Northeastern Nigeria

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Abstract

North-East Nigeria faces acute energy poverty despite its immense solar energy potential. While the theoretical viability of solar photovoltaic (PV) systems is established, a significant gap exists in understanding the actual adoption and power generation on the ground. This study provides a critical empirical assessment of the adoption trends, power generation levels, and factors influencing the deployment of PV systems in North-East Nigeria from 1983 to 2022. Using a snowball sampling technique, primary data was collected via questionnaires administered to 250 solar engineers and marketers, the key stakeholders with expert insight into regional installation and sales. The findings reveal a trajectory of delayed adoption followed by rapid growth. PV adoption was virtually non-existent for the first two decades (1983-2002) due to a lack of awareness and economic constraints. A modest uptake began in the third decade (2003-2012), culminating in an explosive growth phase in the fourth decade (2013-2022), reaching an installed capacity of 6.305 MW. Key drivers for adoption included the desire for energy cost savings, environmental consciousness, and the need for a reliable power source amidst an unreliable national grid. However, formidable barriers persist, primarily the high initial capital cost, prevalent technical difficulties, and a critical shortage of spare parts. This study concludes that while solar PV adoption has recently accelerated, signaling a shift in perception, its sustainable expansion is critically dependent on addressing these economic and technical constraints through targeted policy interventions and market support mechanisms.

Keyword: Solar PV, Adoption, Power Generation, Northeastern Nigeria, Empirical Study.

Introduction

Nigeria faces significant energy poverty challenges, particularly in the North-East region, despite abundant solar resources (Emodi & Boo, 2015; Ladan, 2012). The country's solar potential ranges from 3.5-7.0 kWh/m2/day, with an estimated capacity of 1,189,321.65 MWh for solar PV and 427,829 MW for concentrating solar power in northern states (Ladan, 2012). However, barriers such as high initial costs, lack of technical expertise, and inadequate policies hinder the development of solar energy (Ladan, 2012; Tansu et al., 2022). The energy crisis negatively impacts Nigeria's economic growth, industrial development, and overall socio-economic well-being (Tansu et al., 2022; Emodi & Boo, 2015). To address these challenges, researchers suggest implementing sound policies, feed-in tariffs, technology transfer, and industry collaborations (Ladan, 2012). Effective utilization of renewable energy resources, including solar, could alleviate poverty, create employment opportunities, and promote sustainable development in both urban and rural areas (Nnaji et al., 2010; Emodi & Boo, 2015).

Photovoltaic (PV) systems offer potential as a decentralized and sustainable alternative to unreliable grid power, but their practical implementation faces challenges. Studies have shown that rooftop PV systems in urban areas can provide considerable power without land requirements, though their full potential depends on improved infrastructure and market conditions (Ruan et al., 2023). Decentralized PV systems have demonstrated better grid performance compared to centralized systems, reducing power losses and improving voltage profiles (Khatib & Sabri, 2021). In rural areas, off-grid solar PV technologies can supply basic electricity needs, with market-driven approaches involving local communities showing promise (Sharma et al., 2018). To optimize power output, Maximum Power Point Tracking (MPPT) techniques are crucial, with the Perturb and Observe (P&O) method proving effective in both theoretical and experimental studies (Hussien et al., 2023). However, challenges remain in achieving MPPT under fluctuating natural conditions.

Solar photovoltaic (PV) adoption in Nigeria is influenced by various factors. Drivers include energy poverty, ease of operation and maintenance, government commitment to clean electricity, and increased awareness (Akinola, 2023). Solar PV is seen as a reliable backup against power failures (Jesuleye et al., 2020) and is valued for its convenience and eco-friendliness (Mustapha et al., 2023). However, barriers to adoption persist, such as poor tariff systems, dual subsidies for electricity and petroleum, and lack of finance and economic incentives (Akinola, 2023). The high cost of installation is a major obstacle for over 90% of non-adopters (Mustapha et al., 2023). Additional challenges include inadequate policies for subsidies, difficulty accessing finances, high interest rates, and short loan payback periods (Eronini, 2014). Lack of policy implementation, low public awareness, and absence of organized cooperative groups providing advisory information to potential adopters further hinder solar PV adoption in Nigeria (Eronini, 2014).

Extensive research has established the theoretical potential of solar photovoltaic (PV) systems as a decentralized and sustainable solution to this crisis. Furthermore, existing literature has comprehensively identified the generic barriers to solar adoption in Nigeria, which include high initial costs, lack of financing, inadequate policies, and low awareness (Akinola, 2023; Eronini, 2014; Mustapha et al., 2023). Similarly, studies have detailed the drivers of adoption, such as energy poverty and the need for reliable backup power (Jesuleye et al., 2020; Akinola, 2023). Globally, research has also focused on optimizing PV technical performance through methods like MPPT (Hussien et al., 2023) and understanding household adoption factors like economic considerations and social influences (Kurniawan et al., 2024; Shakeel et al., 2023). However, a critical gap persists between this well-documented potential and the understood generic barriers on one hand, and the on-the-ground reality in North-East Nigeria on the other. There is a significant lack of empirical research that quantitatively measures the actual level of adoption of photovoltaic systems in this specific region and concurrently evaluates the practical level of power generation these installed systems are achieving.

This article therefore moves beyond potential to present a critical investigation into two pragmatic and interconnected issues: the current level of adoption of photovoltaic power systems across the region and the subsequent level of power generation this adoption achieves. And also to find out the factors influencing and or hinder PV adoption in the region.

Study Area

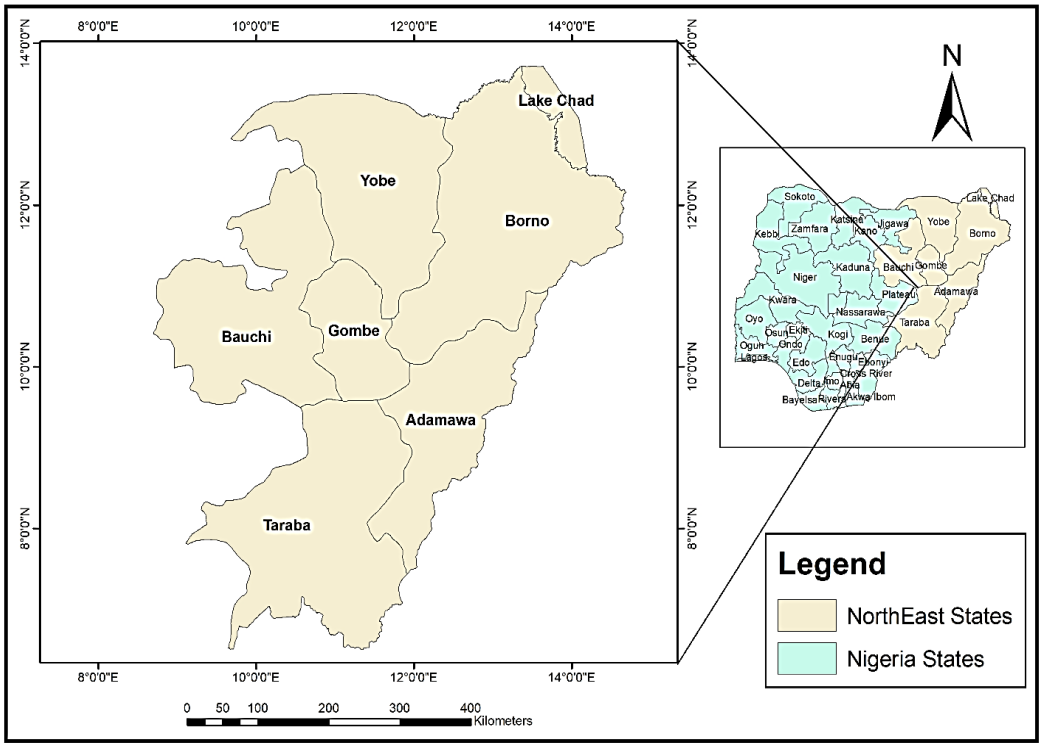


Figure 1: The Study Area.

The North-Eastern Nigeria, often hyphenated to the North-East, is one of the six geopolitical zones of Nigeria, representing both a geographic and political region of the country's northeast. It comprises of six states – Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe. The region is located approximately between **Latitude** 7°30′00″N and 14°00′00″N and **Longitude** 9°30′00″E and 15°00′00″E. The region is geographically diverse, with a range of landscapes from the Sahel savannah in the far north to the tropical rainforests in the south, and several large rivers flowing through it, including the Benue, Gongola, and Yobe Rivers. It is bordered by several states and countries. To the west, it is bordered by the North-West region of Nigeria. To the south, it is bordered by the North-Central region and the East region of Nigeria. Internationally, North-Eastern Nigeria shares land borders with Niger Republic to the north, Chad Republic to the northeast, and the Republic of Cameroon to the east.

The Northeastern Nigeria, a region characterized by its Sudan-Sahelian climate, has historically experienced distinct wet and dry seasons. The wet season, typically spanning May to September, brought annual rainfall ranging from 600 to 1000 mm, while the dry season, from October to April, was marked by arid conditions and the prevalence of the Harmattan winds (Oladipo, 2021). Temperatures in the region averaged between 26°C and 28°C, with relatively stable seasonal patterns that supported traditional agricultural practices and livestock rearing.

In recent decades, however, the region has witnessed significant climatic changes. Rainfall patterns have become increasingly erratic, with annual precipitation declining to 400-800 mm in some areas (Mohammed et al., 2023). This reduction in rainfall has been accompanied by prolonged dry spells and more frequent extreme weather events, such as intense rainfall episodes and heatwaves. Additionally, average temperatures have risen by approximately 0.8°C since the 1960s, exacerbating the challenges faced by the region's predominantly agrarian communities (Abubakar and Ibrahim, 2024). Looking ahead, climate models project further changes in the region's climate. By 2050, temperatures are expected to rise by 1.5°C to 2.5°C, with a 20-30% reduction in annual rainfall. These changes are likely to result in shorter growing seasons, increased frequency of extreme weather events, and heightened vulnerability to climate-related disasters (Hassan et al., 2023).

The impacts of these climatic changes on Northeastern Nigeria are profound, particularly in the areas of agriculture, economy, and infrastructure. Agriculture, the backbone of the region's economy, has been severely affected by declining rainfall and rising temperatures. Crop yields have decreased by 30-40%, and traditional farming calendars have been disrupted, leading to increased crop failures and reduced livestock productivity (Yakubu, 2024). These challenges have, in turn, contributed to food insecurity and rising food prices, further straining the region's economy. Economically, the decline in agricultural productivity has led to a 25% reduction in the sector's contribution to the region's GDP (World Bank, 2023). Many farming communities have been forced to migrate in search of better opportunities, leading to demographic shifts and increased pressure on urban centers. The rising cost of agricultural insurance and the need for climate-resilient farming practices have further burdened the region's already fragile

economy. Infrastructure in Northeastern Nigeria has also been significantly impacted by climate change. Extreme rainfall events have damaged roads, bridges, and urban drainage systems, while prolonged dry spells have stressed water infrastructure. The need for climate-resilient construction and increased maintenance costs has placed additional strain on the region's limited resources (Ibrahim et al., 2024).

The vegetation in North-East Nigeria is primarily characterized by the Sahel savanna and the Sudan savanna (Abaje et al., 2020). The Sahel savanna, found in the northern parts of the region, is a semi-arid transitional zone between the Sahara Desert and the more fertile southern regions (Buba et al., 2023). This area features sparse vegetation, dominated by drought-resistant grasses, shrubs, and scattered trees (Ojoye et al., 2021). In contrast, the Sudan savanna, located further south, consists of tropical grasslands with denser vegetation, including taller grasses and a wider variety of trees and shrubs (Akinsanola et al., 2022). These vegetation zones are dynamic and have been shifting due to climate change and human activities, such as deforestation and overgrazing (Odjugo, 2021). Notably, desertification remains a critical environmental challenge, with the Sahara Desert expanding southward into the Sahel (Buba et al., 2023).

The aridity gradient in North-East Nigeria varies significantly, with the northern Sahelian areas experiencing higher aridity, prolonged dry seasons, and minimal rainfall (Abaje et al., 2020). This creates semi-desert conditions with limited vegetation cover. In contrast, the southern Sudan savanna receives more rainfall and has a shorter dry season, supporting denser and more diverse plant species (Akinsanola et al., 2022).

North-East Nigeria contains several ecologically and economically significant wetland regions. The Hadejia-Nguru wetlands, located in Yobe State, form a vast floodplain in the Sudano-Sahelian zone, a transitional belt between the Sudanian Savanna (south) and the Sahel (north) (Mohammed et al., 2023). These wetlands, including Nguru Lake, support biodiversity, agriculture, and fisheries but face threats from declining rainfall, population pressure, and upstream dam construction (Dami et al., 2021).

The most critical wetland in the region is Lake Chad, a freshwater lake shared by Nigeria, Niger, Chad, and Cameroon. Historically, Lake Chad covered 28,000 km² in the 19th century, but climate change and excessive water extraction have reduced it to less than 10% of its 1960s size (UNEP, 2022). The lake's basin spans 1 million km², fed mainly by the Chari River (south) and the seasonal Komadugu-Yobe River (northwest) (Okonkwo et al., 2020). As a lifeline for over 30 million people, its drastic shrinkage has triggered food insecurity, migration, and conflicts (Bila & Ajibola, 2023).

Material and Method

The data used to achieve this study was a primary data collected via questionnaire. The targeted population was the marketers who sell the equipment/materials and engineers/technicians who installed and maintain the system. The targeted population for this study comprised engineers responsible for installing Solar PV systems and marketers involved

in selling the related materials. These two groups were selected as the primary audience due to their direct involvement in the sale and installation processes. They possess comprehensive knowledge of all individuals who have installed the systems in residential or office settings. Given the extensive scope of the study area, it is impractical to reach every household equipped with the system.

The study employed the snowball sampling technique due to the initial ambiguity regarding the target population. A total of 250 responses were recorded. The primary objective was to gather as many responses as possible. However, it became evident that the targeted respondents were nearing exhaustion as the number of responses approached 200. Upon reaching 250 responses, the research concluded that the target population was nearly exhausted, with over 75% of the population having been reached. This sample size was deemed sufficient to represent the entire population.

Method of Data Analysis

The data analysis involved basic statistics on a spreadsheet excel. The Data analyzed and presented with the use of descriptive statistics: tables and charts to illustrate the changes in adoption pattern and level of power generated over the time.

The resulting findings are detailed in 3 subheading: (i) Temporal Trend in Photovoltaic Power (PVP) Adaption in North-East Nigeria: An Insights from Engineers and Marketers, (ii) Photovoltaic Power Generation in North-East, Nigeria and (iii) Factors Influencing the Installation Trends of PV Solar Panels in Northeast Nigeria.

Results

Table 1: PV Solar panel adoption Trend in North East, Nigeria.

S/N	Questions	Response Summary
1	**total number of participants**	250
2	**number of engineers and marketers**	160 engineers and 90 marketers
3	**when did you ventured into solar PV business?**	205 respondents started 2013 – 2022, 39 respondents started 2003 – 2012. While 6 started 1993 – 2002.
4	**Total installed/sell capacity**	6.5MW: 195KW in 3rd dec while 6.305MW in the 4th decade
5	**Awareness and knowledge**	215 of the respondents are specialists while 35 concentrate on the market
6	**Adoption trend**	230 participants adopted the use of solar PV in their houses and or shops, while the remaining 20 did not adopt the usage of the system in their houses. They all adopt the system between 2013 and 2022

6b	**when did you first adopt PV technology?**	First adoption: 2013-2022
6c	**what is the reasons for not adopting**	High initial cost (20 respondents)
7	**Factors Influencing Adoption**	150 spondents: Environmental consciousness, Energy cost savings, Reliability of PV systems, Availability of sunlight, 55 respondents: Environmental consciousness, Energy cost savings, Availability of sunlight while 45 respondents: Selected energy cost saving and availability of solar radiation are the factors influencing Solar PV adoption
8	**Challenges and Barriers**	180 respondents: Lack of spare parts, intermittent power supply, technical difficulties while 50 respondents said Technical difficulty as the challenge faced by Solar PV adoption

Source: Field survey (2024).

Temporal Trend in Photovoltaic Power (PVP) Adaption

From Table 1, the trend of adoption patterns among specialists in charge of PV solar panel sales, installs, and maintenance were revealed.

This report focuses on the adoption trends among experts who are in charge of PV solar panel sales, installations, and maintenance. Through a four-decade analysis of the data, the study identified patterns, obstacles, and possibilities associated with PV adoption. No adoptions were recorded in the early years (1983–1992). In Northeast Nigeria, engineers and marketers did not embrace PV power systems at all during the first ten years, which ran from 1983 to 1992. This lack of participation implies that the region has not yet seen a major uptake of PV technology. Economic limitations, a lack of infrastructure, and low awareness were perhaps some of the factors that caused this initial standstill. Slow Progress in the second decade (1993-2002): Interest Beginning to Emerge during the second decade (1993–2002), six cases of moderate adoption were recorded showing the people in the region started to venture in the emerging field. This suggests a change toward increased interest in and involvement with PV systems, even though it is still relatively modest. Though cautiously, engineers and marketers probably started looking at the advantages of solar energy.

Rapid Growth in the third decade (2003–2012): Market penetration and awareness. There was a notable increase in PV usage over the third decade (2003-2012), as there were 39 personnel comprising technicians and the marketers. This increase is a result of better market circumstances and increased knowledge of renewable energy options. The benefits of photovoltaic (PV) systems, such as their potential cost savings, environmental sustainability, and less reliance on fossil fuels, are becoming more widely acknowledged by engineers and marketers. Adoption accelerated at this time by public policy, educational programs, and commercial sector expenditures. Outstanding Growth (2013–2022): The PV Solar Panel Industry Succeeds. In Northeast Nigeria, the fourth decade (2013–2022) was a turning point

for the adoption of PV. The adoption rate increased significantly to 205 cases, showing significant expansion. PV technology was eagerly adopted by engineers and marketers who wanted to profit from improvements in panel efficiency, cost, and dependability.
Figure 2 shows the dynamic trajectory of PV adoption among engineers and marketers shows a temporal distribution that progresses from early reluctance to strong participation. In order to hasten Northeast Nigeria's transition to a greener and more resilient energy environment, it is imperative that sustained investments be made in renewable energy infrastructure, capacity building, and cooperative initiatives.

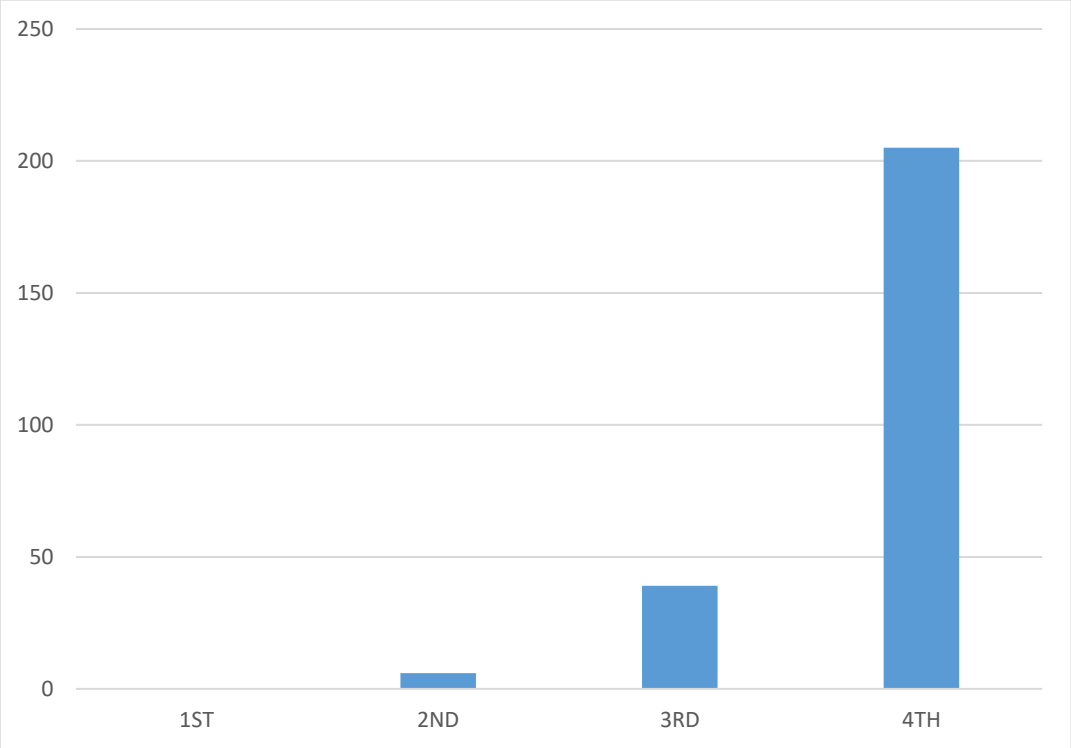


Figure 2: the trend of PV solar panel adoption in North-Eastern Nigeria.
Source: Field Survey (2024)

Photovoltaic Power Generation in North-East, Nigeria
The installation trends of PV solar panels and subsequent power generation through the installed panels in Northeast Nigeria over four decades were investigated, from 1983 to 2022. The results were presented in figure 3, which summarizes the total generated power (in megawatts) during each decade. During the first decade (1983-1992), no PV installations were recorded subsequently, there was no power generated from the system. Similarly, the second decade (1993-2002) continued to witness zero installations. However, the third decade (2003-2012) saw a modest start, with 0.195 MW (translating to 195KW) of installed capacity. Finally, the fourth decade (2013-2022) marked a substantial leap, with 6.305 MW of installed PV capacity. The total installed power capacity in the study area is displays in figure 3

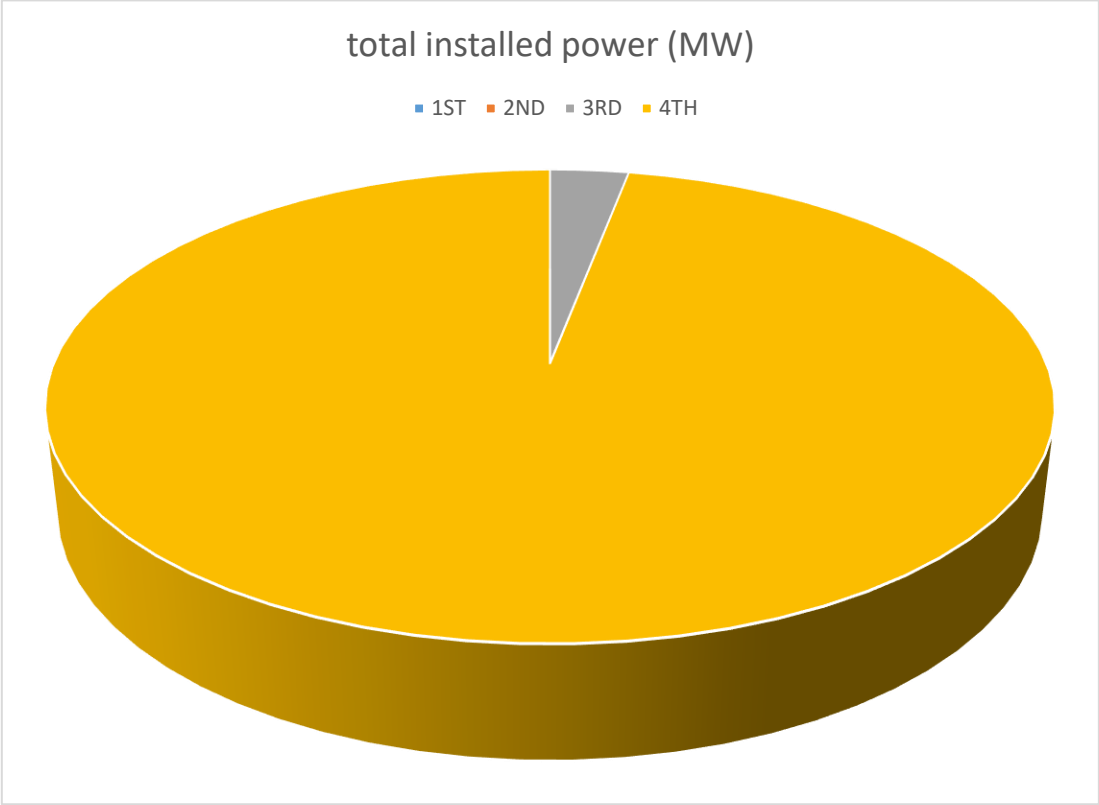


Figure 3: Photovoltaic Power generation from 1983 to 2022
Source: Research Analysis

Factors Influencing the adoption of PV system in Northeast Nigeria

The adoption of photovoltaic (PV) solar system in Northeast Nigeria has witnessed significant growth. Understanding the underlying factors driving this trend is crucial for sustainable energy development. From the survey carried out, here are the factors influencing the adoption of PV solar system in Northeast Nigeria from the respondents.

The respondents highlighted several underlying factors influencing the adoption trends of PV solar panels in Northeast Nigeria. Regarding awareness and knowledge of the system, 215 respondents identified as specialists in the installation and maintenance of PV systems, while 35 were amateurs, focused on sales but not proficient in installation and maintenance. They confirmed that the general public is largely aware of PV system developments.

The respondents identified various motivational factors driving the adoption of PV systems. Specifically, 150 respondents cited environmental consciousness, energy cost savings, system reliability, and the availability of sunshine throughout the year as key drivers. However, 69 respondents agreed with these factors but excluded reliability as a significant influence on adoption. Another 31 respondents believed that energy cost savings and the availability of sunshine were the primary reasons for PV system adoption. They noted that in rural areas

without connections to grid, residents adopt PV systems to light their homes and for irrigation purposes.

The engineers also discussed the challenges facing the acceptance of PV systems. A total of 180 respondents pointed to technical difficulties, intermittent power supply, and a lack of spare parts as major obstacles to adoption. Additionally, 50 respondents identified high initial costs and technical difficulties faced by users as the primary challenges in Northeast Nigeria.

The satisfaction level with PV systems among engineers and end-users was also assessed. Of the respondents, 218 expressed high satisfaction with the system, reporting that their clients were pleased with the results and recommended PV systems to others. However, 32 respondents, while satisfied, expressed some complaints and were not strongly satisfied.

These findings suggest that while there is significant awareness and a strong motivation to adopt PV systems driven by environmental and economic factors, challenges such as technical difficulties and high initial costs need to be addressed to enhance adoption rates further.

Discussion of Results

This study set out to critically investigate the pragmatic issues of adoption levels and power generation from photovoltaic (PV) systems in North-East Nigeria, moving beyond the well-documented potential and generic barriers. The findings reveal a compelling narrative of delayed ignition followed by rapid, yet fragile, growth, shaped by a complex interplay of global trends, regional realities, and persistent local challenges.

The most striking finding is the clear temporal trajectory of adoption. The complete absence of recorded installations in the first two decades (1983-2002) aligns perfectly with the broader Nigerian context described by Ladan (2012) and Emodi & Boo (2015), where energy poverty was pervasive but unmet by renewable solutions due to economic constraints, a lack of infrastructure, and negligible awareness. The modest uptake of 195 kW in the third decade (2003-2012) signals an emerging awareness, likely spurred by initial policy discussions and gradual technological advancements globally. However, the explosive growth in the fourth decade (2013-2022), with installations skyrocketing to 6.305 MW, represents a pivotal shift. This surge can be attributed to a confluence of factors: a critical worsening of grid reliability, a global reduction in PV module costs as noted by Wilson (2020), and increased regional awareness of solar technology as a viable alternative. This pattern mirrors the global exponential growth described by Haegel et al. (2019) and Kruitwagen et al. (2021), albeit on a much smaller and delayed scale, highlighting how global market trends eventually trickle down to influence local adoption.

The drivers of adoption identified by respondents—energy cost savings, environmental consciousness, reliability, and abundant sunlight—confirm and contextualize the findings of previous research. The prioritization of cost savings and reliability over environmental benefits underscores the economic and practical motivations of adopters in a developing economy facing severe energy shortages, as noted by Jesuleye et al. (2020) and Akinola (2023). The abundance of sunlight, the region's primary natural asset, is correctly perceived

as the foundational enabler. However, the discussion around reliability is dual-edged; while PV is adopted for its perceived reliability compared to the grid, the study uncovers that technical failures and a lack of spare parts subsequently become a major source of unreliability, creating a significant paradox.

This leads to the core challenge threatening the sustainability of this growth: the critical barriers of high initial cost, technical difficulties, and a lack of spare parts. The high initial cost remains the single greatest barrier to wider adoption, a finding consistent with Mustapha et al. (2023) and Eronini (2014). This is exacerbated in North-East Nigeria by lower average incomes and economic instability. More alarmingly, the prevalence of technical issues and an unreliable supply chain for spare parts, as reported by 180 respondents, creates a vicious cycle. Systems that fail cannot be repaired quickly, leading to dissatisfaction, undermining confidence in the technology, and stifling the word-of-mouth recommendations that are crucial in this market. This finding resonates with the warnings of Campton (2022) about the risks of varying component quality and inadequate installer training in developing countries. It suggests that the rapid market expansion has outpaced the development of a supporting ecosystem of skilled technicians and quality-assured components, a necessary factor for long-term viability as emphasized by Klise (2014).

Furthermore, the fact that a segment of respondents (69) did not cite "reliability" as a driver, coupled with the 32 respondents who reported only moderate satisfaction, indicates that the lived experience of PV ownership does not always meet the initial expectation of a set-and-forget solution. This satisfaction gap is crucial; it identifies the point where expectation (driven by the promise of solar) clashes with reality (shaped by maintenance challenges), a dynamic noted by Karakaya et al. (2015) and Kansal (2016) in other developing contexts.

In conclusion, the results indicate that North-East Nigeria is in a critical phase of its energy transition. The adoption of PV technology has moved from theory to practice, demonstrating significant potential to alleviate energy poverty. However, the current growth model is vulnerable. The market's foundation is shaky, built more on immediate necessity than on a robust, sustainable ecosystem. The journey from first adoption to long-term sustainability now depends less on further awareness and more on strategic interventions that address the hard constraints of finance, technical capacity, and supply chain integrity. Without these interventions, the region risks a plateau in adoption and a degradation of existing systems, ultimately failing to harness its vast solar potential for sustainable development.

Conclusion and Recommendations

This study provides a critical empirical assessment of the adoption and performance of photovoltaic (PV) systems in North-East Nigeria, moving beyond theoretical potential to present the on-the-ground reality. The findings reveal a story of remarkable recent growth emerging from a prolonged period of stagnation. The investigation confirms that PV adoption was virtually non-existent in the region for the first two decades (1983-2002), a period characterized by a lack of awareness, significant economic constraints, and an underdeveloped

market. The third decade (2003-2012) marked a tentative beginning with modest uptake, which then exploded in the fourth decade (2013-2022). This recent and rapid growth, culminating in an installed capacity of 6.305 MW, demonstrates a significant shift in perception and a growing reliance on solar technology as a practical solution to the region's acute energy poverty.

The drivers of this adoption are clearly identified by stakeholders. The primary motivators include a strong desire for energy cost savings, heightened environmental consciousness, and the critical advantage of having a reliable power source in an area plagued by an unreliable national grid. The abundant availability of sunlight in the region is rightly perceived as a foundational asset making these benefits possible. However, this promising growth is severely constrained by significant barriers that threaten the sustainability and further expansion of the PV market. The most formidable challenges include the high initial capital cost of systems, which remains a primary deterrent for a larger segment of the population. Furthermore, the market is plagued by a prevalence of technical difficulties faced by users, a critical shortage of spare parts, and a lack of sufficiently trained technicians, leading to intermittent system failures and eroding user confidence.

In essence, while North-East Nigeria has successfully begun its transition towards solar energy, the journey is far from complete. The current level of adoption, though impressive compared to its own history, remains a fraction of the region's vast solar potential. The sustainability of existing systems and the acceleration of future adoption are contingent upon directly addressing the identified barriers of cost, technical support, and supply chain reliability.

Recommendations

To consolidate the gains achieved in the last decade and catalyze further growth, a multi-faceted approach involving policymakers, financial institutions, and industry stakeholders is urgently required. Firstly, federal and state governments should develop and implement targeted policy interventions. These could include introducing subsidy programs or soft loans specifically designed for solar acquisitions to mitigate the barrier of high initial cost. Additionally, establishing and enforcing minimum quality standards for imported PV components and certification programs for installers would significantly improve system reliability and build consumer trust.

Secondly, addressing the technical and maintenance challenges is crucial for sustaining the existing market. This can be achieved by supporting the establishment of a robust local supply chain for quality spare parts and investing in the capacity building of local technicians through standardized training programs. Encouraging solar companies to offer affordable long-term maintenance and warranty packages would also provide users with much-needed technical security and improve overall satisfaction.

Finally, continuous public awareness campaigns are needed to educate potential adopters on the long-term economic benefits of PV systems, beyond the initial cost, and to guide them in

making informed decisions regarding system quality and installation. By implementing these recommendations, stakeholders can work together to overcome the existing barriers, ensure the longevity and performance of installed systems, and unlock the full potential of solar energy to drive sustainable development and improve the quality of life for the people of North-East Nigeria.

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