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Renewable Energy Integration: The Influence of Solar Systems in Nigeria's Power Supply Schemes and Dependability

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Abstract

Nigeria's power sector faces persistent challenges in ensuring a dependable and stable energy supply, impacting economic growth and quality of life. Renewable energy, particularly solar systems, presents a promising avenue for addressing these challenges. This paper explores the role of solar energy systems in improving the reliability and stability of Nigeria's power supply schemes. The study examines the current state of solar systems integration, assessing its contributions to rural electrification and urban development. It further analyzes the economic and cost benefits of successful solar adoption while highlighting challenges such as infrastructure deficits, regulatory bottlenecks, and financial constraints. By investigating the effectiveness of recent policy measures and technological advancements, the paper evaluates how these factors have reshaped the solar energy landscape in Nigeria and enhanced the Nigeria's supply schemes. Using case studies, data-driven insights, and policy analysis, this research aims to provide actionable recommendations to optimize solar systems integration for a more sustainable and reliable energy future in Nigeria.

Keywords: Renewable Energy Integration, Solar Systems, Nigeria's Power Supply Schemes

1. Introduction

Every living thing deserves the right to a clean-living environment. This statement means a clean place to live, clean air to breathe, clean water, and a clean place to reproduce. With widespread fossil fuel (coal, oil and natural gas) use, these basic rights have been diminished for living things, especially in the countries where the dependence on fossil fuel for energy is virtually absolute. The extraction and burning of fossil fuel for energy purposes results in the emission of greenhouse gases and pollution of air, water and soil and this can mean extinction for certain animals and plants, as well as diseases, birth defects, and death for humans. To reduce the dependency on fossil fuels and mitigate climate change, renewable energy integrations have emerged as a promising solution in the quest for sustainable energy and cleaner environment to live in.

The energy sector in Nigeria has long been plagued by instability, insufficient infrastructure, and a dependence on fossil fuels. Power outages and unreliable supply are frequent, hindering development across various sectors. According to [1] Nigeria has the world's largest absolute electricity access deficit. Lack of access to the electricity grid affects 45 % of the population (about 90 million people), making Nigeria the country with the largest number of people not connected to electricity. As such, Nigeria accounts for 12 % of the global access deficit. Large disparities exist in access to electricity between urban areas (84 %) and rural ones (26 %). The net access deficit has increased by over seven million citizens over the last decade, as the pace of population growth has overtaken the pace of electrification. Increasing population without commensurate increase in energy infrastructure poses greater threat to electricity access, it stability and reliability. Power outages are common occurrence as result of system instability occasioned by the widening gap between electricity supply and demand, with some areas experiencing hours or even days without electricity supply. Due to the unreliable national grid, Nigeria has one of the highest rates of self-generated electricity system in Africa, with individuals and businesses using over *14 GW* of privately ownedgenerators (diesel or petrol generators). This self-generation represents more than twice the capacity provided by the

national grid, exacerbating the high cost of doing business and living. To address these issues, there has been a significant interest in renewable energy, particularly solar power, due to its potential to provide a sustainable and decentralized source of electricity. *Renewable energy integration refers to the process of connecting renewable energy sources such as solar, wind, hydro, geothermal, and biomass, into the existing energy grid. Effective renewable energy integration ensures reliable, stable, efficient and sustainable energy supply.* This paper aims to explore the impact of solar systems in improving Nigeria's power supply scheme and it reliability, focusing on their role in the current energy infrastructure, the challenges of integration, and the opportunities for a more resilient energy future.

2. Literature Overview

This section will provide the overview of literatures in relation to the subject.

2.1 Current State of Solar Systems Integration

Nigeria's energy sector has been characterized by an overreliance on fossil fuels, leading to environmental concerns and an unstable power supply. In recent years, there has been a concerted effort to diversify and increase energy mix in Nigeria by integrating renewable energy sources, particularly solar power. There have been varying levels of solar energy integration, ranging from small-scale rural electrification projects to urban solar power systems. While solar energy offers clear benefits in terms of sustainability, its integration into the national grid has been hindered by factors such as insufficient infrastructure, financial limitations, and regulatory challenges. The National Renewable Energy and Energy Efficiency Policy (NREEEP), launched in 2015, aims to increase the share of solar energy in Nigeria's energy mix, targeting 3% by 2020 and 6% by 2030. Despite these policy initiatives, the actual integration of solar energy has been sluggish. As of the year 2024, Nigeria continues to experience frequent power outages, with the national grid facing multiple collapses annually. The country generates and distributes only a third of its 13,500 MW energy capacity, despite its vast gas reserves and potential for renewable energy production [15]. Small-scale solar solutions have gained traction, especially in rural areas where grid access is limited. Companies like Sun King have expanded significantly, providing micro-solar systems and training thousands of sales representatives. However, large-scale solar projects have struggled due to Nigeria's challenging business environment, high borrowing costs, and inadequate climate finance. However, the integration of solar systems in Nigeria is evolving with growing adoption and recent policy support such as:

1. Growing Adoption: There is a significant increase in the installation of solar home systems, with 88% of users reporting improved quality of life.
2. Policy Support: Recent government initiatives and policies are aimed at promoting renewable energy, enhancing the integration of solar systems into the national grid.

2.2 Specific Roles of Solar Systems in Nigeria's Power Supply

The integration of solar systems into Nigeria's power supply system has evolved over the years, reflecting a growing recognition of their potential to address critical challenges such as electricity shortages, grid instability, and energy access disparities. Below are some of the specific roles solar systems play in Nigeria's existing power supply system:

1. Bridging the Electricity Access Gap
   Nigeria faces significant energy poverty, with approximately 85 million people lacking access to electricity [16]. Solar systems, particularly off-grid solutions, play a critical role in extending electricity access to underserved urban and rural areas where grid extension is economically or geographically not feasible. Initiatives such as the Rural Electrification Agency (REA) projects have deployed solar mini-grids and solar home systems to power homes, schools, and healthcare facilities in remote communities thereby bridging the electricity access gap in the country.
2. Enhancing Energy Reliability and Decrease in Grid Dependency
   Frequent grid failures and outages are significant issues with the Nigeria's power sector [9]. Solar energy systems, including grid-connected photovoltaic (PV) systems and hybrid systems (solar integrated with backup generators or battery storage), provide a more reliable alternative source by supplementing the unstable central grid. Businesses and households increasingly adopt rooftop solar installations to ensure consistent power supply during outages, reducing downtime and economic losses and also, reduction on over dependency on the central grid.
3. Supporting Decentralized Power Generation
   Solar systems contribute to Nigeria's shift from a centralized power system to a decentralized one. This shift aligns with global trends in energy transition and enhances overall system resilience. Decentralized solar installations, such as mini-grids and independent solar PV systems, reduce transmission and distribution losses, which are prevalent in the national grid due to aging infrastructure [15].
4. Providing Clean and Sustainable Energy
   Solar systems represent a cleaner energy alternative to Nigeria's reliance on fossil fuels for electricity generation. The integration of solar energy helps mitigate greenhouse gas emissions, contributing to Nigeria's commitments under the Paris Agreement and the Energy Transition Plan [16]. The adoption of solar PV in urban areas, such as Lagos and Abuja, has demonstrated the potential to significantly reduce reliance on diesel generators, which are a major source of air pollution.
5. Driving Economic Growth and Job Creation
   The solar energy sector has emerged as a key driver of economic activity and job creation in Nigeria. The deployment, operation, and maintenance of solar systems create jobs, particularly for youth and small businesses. Moreover, solar-powered solutions enable productivity in sectors like agriculture (e.g., solar irrigation systems) and small-scale manufacturing, fostering economic growth in both rural and urban settings [9].
6. Promoting Resilient Public Infrastructure
   Solar systems are increasingly being integrated into critical public infrastructure to ensure functionality during power outages. For instance, solar-powered water pumps, streetlights, and healthcare facilities are

enhancing public service delivery and reducing dependence on expensive and unreliable grid electricity.

7. Contributing to Energy Security
   Solar systems help diversify Nigeria's energy mix, reducing over-reliance on traditional power sources such as gas-fired and hydropower plants. This diversification strengthens energy security by providing a renewable, locally sourced, and inexhaustible energy option [15].

2.3 Current Progress and Key Projects

The Nigerian government and international organizations have implemented several notable projects to promote solar systems integration, including but not limited to:

1. Nigeria Electrification Project (NEP): Led by the Rural Electrification Agency (REA) and supported by the World Bank, this project focuses on deploying solar mini-grids and stand-alone solar systems in off-grid areas [15].
2. Solar Power Naija Program: Part of the Economic Sustainability Plan, this program aims to install 5 million solar home systems to serve 25 million Nigerians by 2026.
3. Lagos Solar Project: A government initiative to power schools, healthcare facilities, and public buildings in Lagos State using solar energy.

2.4 Challenges and Opportunities in Solar Energy Integration

A. Challenges:

1. Infrastructure Deficits: Nigeria's aging infrastructure in power sector hampers the integration of renewable energy sources. Frequent grid failures and limited transmission capacity pose significant obstacles to the adoption of solar energy [15].
2. Regulatory Bottlenecks**:** Navigating the regulatory landscape for distributed solar power in Nigeria is complex. While policies like NREEEP exist, their implementation has been inconsistent, creating uncertainty for investors and developers.
3. Financial Constraints: High initial capital costs and limited access to financing deter both consumers and investors from adopting solar technologies. Additionally, the government's refusal to provide essential guarantees to developers has stalled major solar projects.

B. Opportunities:

1. **Decentralized Energy Solutions:** The Nigerian government, in collaboration with the World Bank, is working to establish 1,000 mini solar grids to improve rural electricity access. This decentralized approach can enhance resilience and provide reliable electricity to underserved and unserved communities [15].
2. **Public-Private Partnerships:** Collaborations between the government and private sectors have led to significant infrastructure projects development in solar energy integration in Nigeria. For instance, Huawei has committed to establishing a joint solar PV test laboratory in Nigeria, and a Chinese firm plans to set up an assembly plant for electric tricycles, contributing to renewable energy development [7].
3. **Technological Advancements:** Recent developments in solar technology, such as improved panel efficiency and energy storage solutions, have made solar energy more accessible and cost-effective. These advancements can facilitate the integration of solar systems into Nigeria's energy mix as the country strive to stable and balance the power sector.

2.5 Impact of Technological Advancements and Policy Changes on Solar Energy Integration in Nigeria

Technological advancements and policy changes are instrumental in shaping the solar energy landscape in Nigeria. These developments directly influence the feasibility, efficiency and scalability of solar integration efforts across the country. In furtherance, we will discuss recent technological advancements, key policy changes that have facilitated or hindered solar energy integration, and examples of how outdated policies were replaced by more supportive frameworks.

2.5.1 Technological Advancements in Solar Energy Integration

1. The Rise of Pay-As-You-Go (PAYGO) Solar Systems
   These systems offer a way to access clean energy by making regular payments, rather than requiring a large upfront investment, and are particularly popular in areas with limited access to electricity. PAYGO is a business model that allows customers to obtain a solar home system (for lighting, phone charging, etc.) with regular payments, often using mobile money, until they own it.
2. Improved Photovoltaic (PV) Technologies
   Recent years have seen the deployment of next-generation of solar panels with higher efficiency and durability in Nigeria. For example, bifacial solar panels that can capture sunlight on both sides are being adopted in large-scale installations, significantly increasing energy output [15]. This technology has been instrumental in improving the cost-effectiveness of solar mini-grids in rural areas. The introduction of flexible and lightweight solar modules has allowed installations in unconventional settings, such as urban rooftops and small public spaces.
3. Battery Storage Innovation
   Advanced lithium-ion battery systems have begun to replace older lead-acid batteries, offering longer lifespans, better energy density, and reduced environmental impact. This advancement is critical for off-grid solar systems, particularly in rural electrification projects. For example, Tesla's Powerwall systems and similar products have been introduced to Nigeria, enabling businesses and households to store solar energy more effectively for use during nighttime or outages.
4. Smart Grid and Digital Monitoring Technologies
   The use of smart inverters and grid-tied solar systems has improved the integration of solar energy into the national grid. These systems ensure grid stability and allow real-time monitoring of energy usage. Companies like Resource Energy have incorporated IoT (Internet of Things) devices into solar solutions, enabling remote monitoring and predictive maintenance for mini-grid installations [15].
5. Solar-Driven Agriculture and Industry
   Solar irrigation systems have been introduced to support agricultural productivity in states like Kano and Kaduna. These systems integrate solar-powered water pumps with automated controls for efficient and effective irrigation, addressing challenges in

agricultural power reliability and stability. Industrial-scale solar cold storage systems are now being used to preserve perishable goods in markets of major cities like Lagos and Port Harcourt.

2.5.2 Policy Changes Supporting Solar Integration

Policies that have Accelerated Solar Integration are but not limited to:

1. Nigeria Electrification Project (NEP)
   This World Bank-funded program, launched in 2019 and still ongoing, aims to deploy solar mini-grids and standalone systems to rural areas. The project has led to the electrification of over one million households using solar solutions, with plans to expand further [3].
2. Solar Power Naija Program
   Initiated in 2020 under the Economic Sustainability Plan, this program targets the installation of five million solar home systems to provide electricity to twenty-five million Nigerians by 2026. It has also created thousands of jobs in the renewable energy sector.
3. Tax Incentives for Solar Components
   The Federal Government has introduced import duty exemptions and tax holidays for solar PV panels, batteries, and related components. These measures have reduced costs for renewable energy providers and encouraged investment in solar solutions.
4. National Renewable Energy and Energy Efficiency Policy (NREEEP)
   Revised in 2023, the NREEEP sets a target for renewable energy to constitute 30% of Nigeria's electricity mix by 2030, emphasizing the role of solar energy in achieving this goal.
5. Energy Transition Plan
   Nigeria's Energy Transition Plan (ETP), launched in 2022, outlines a pathway to achieve net-zero emissions by 2060. Solar energy plays a central role, with policies focused on expanding decentralized solar installations and integrating solar energy into the national grid [16].
6. The Nigerian Electricity Act 2023
   This Act allows Nigerian states, companies and individuals to generate, transmit, and distribute electricity, while restricting interstate and transnational distribution. It also promotes private investment through various licensing options and prioritizes renewable energy integration into the grid.

2.5.3 Policies That Have Hindered Solar Integration in Nigeria

1. Inconsistent Regulatory Frameworks
   Previous policies, such as the 2006 Renewable Energy Master Plan (REMP), failed to achieve their targets due to inadequate implementation, lack of coordination, and insufficient funding mechanisms. For example, REMP aimed to increase solar power generation but did not provide specific incentives for private sector participation, leading to limited uptake.
2. Bureaucratic Challenges
   Complex licensing processes for Independent Power Producers (IPPs) and mini-grid operators under the Electric Power Sector Reform Act (2005) discouraged small-scale solar projects. The lack of clear guidelines for integrating solar energy into the national grid further hindered the progress.
3. High Import Tariffs
   Prior to recent reforms, high import tariffs on solar components inflated costs, making solar solutions unaffordable for many households and businesses.

2.5.4 Policy Replacements and Updates

1. Mini-Grid Regulation
   The 2016 Mini-Grid Regulation, developed by the Nigerian Electricity Regulatory Commission (NERC), created a supportive framework for mini-grid developers. Updates in 2021 included simplified licensing for mini-grids serving up to 1 MW, incentivizing private sector investments in solar projects.
2. Removal of Import Tariffs
   The removal of import tariffs on solar panels and components in 2020 under the Customs and Excise Tariff (Variation) Amendment Order significantly reduced the cost of solar installations.
3. Grid Code Updates
   NERC revised the grid code in 2022 to accommodate distributed generation systems, including solar PV systems, enabling smoother integration into the national grid.

2.5.5 Policy and Technology Alignment

The Lagos State government partnered with private companies to install solar panels on public schools and healthcare facilities under the Lagos Solar Project, leveraging both modern solar technology and updated tax incentives. The Federal Government's collaboration with the African Development Bank (AfDB) and Power Africa facilitated the deployment of high-efficiency mini-grids using advanced PV modules in Northern Nigeria, showcasing the synergy between policy and technology [9].

Technological advancements and progressive policy reforms have created significant opportunities for solar energy integration in Nigeria. However, challenges such as policy inconsistency, inadequate funding, and limited public awareness must be addressed to unlock the full potential of solar energy in transforming Nigeria's power sector.

3. Methodology

This research adopted the descriptive analysis method that incorporated a mixed approach to gather both qualitative and quantitative data on the integration of solar systems in Nigeria. The study includes:

1. Case Studies: Analyzing solar energy integration in various Nigerian states, particularly focusing on private users.
2. Surveys and Interviews: Engaging solar power users and installers to gather insights on challenges and opportunities in solar systems integration.
3. Data Analysis: Reviewing available data on the cost benefits, economic impacts, and policy effectiveness related to solar systems adoption.

4. Results and Discussions

The method presents following results and discussions

4.1 Result and discussion of Case Studies

The results are presented as case studies with detailed discussions of each case study.

Case Study 1: Reducing Operational Costs in a Small Business – Edo State, South- South Nigeria

Background:

Mrs. Omonye, a small business owner in Edo State, runs a Supermarket that relied heavily on the national grid and a diesel generator due to frequent power outages. High fuel

costs and inconsistent electricity significantly affected her operational costs and productivity.

Solar System Details:

1. Type: Hybrid system (5 kW solar PV with battery storage and grid backup).
2. Duration of Use: 3 years.
3. Motivation: High electricity costs and frequent outages.

Impact:

1. Cost Savings: Mrs. Omonye reported a 50% reduction in electricity expenses, primarily due to reduced generator usage.
2. Reliability: The hybrid solar system provided consistent power during grid failures, allowing uninterrupted business operations.
3. Challenges: She faced maintenance issues with her inverter but resolved them through local technicians.

Solar energy has significantly improved the reliability and cost-effectiveness of Mrs. Omonye's business operations. However, occasional maintenance challenges highlight the need for more accessible technical support in urban areas.

Case Study 2: Enhancing Energy Access in Rural Communities – Ebonyi, South-East Nigeria

Background:

Mr. Okafor, a resident of a rural village in Ebonyi State, faced severe electricity shortages due to limited grid coverage. His household previously relied on kerosene lamps and a small petrol generator, both of which were costly and environmentally harmful.

Solar System Details:

1. Type: Off-grid system (3 kW solar PV with battery storage).
2. Duration of Use: 4 years.
3. Motivation: Lack of grid access and high fuel costs.

Impact:

1. Improved Quality of Life: Solar power provided 24/7 electricity, improving household comfort, enabling children to study at night, and reducing reliance on kerosene.
2. Health and Environmental Benefits: Eliminating kerosene lamps improved indoor air quality, and solar adoption reduced the family's carbon footprint.
3. Challenges: The rainy season significantly reduced power generation, highlighting the need for quality and optimal design, technical know-how and better storage solutions.

Off-grid solar systems have transformed energy access for rural households like Mr. Okafor's, offering economic, environmental, and health benefits. However, seasonal variability in power generation remains a key challenge.

Case Study 3: Solar Power Adoption in Educational Institutions – Abuja, North-Central Nigeria

Background:

GreenLight Academy, a private secondary school in Abuja, experienced frequent blackouts that disrupted classes and administrative work. The school sought sustainable energy solutions to ensure uninterrupted learning.

Solar System Details:

1. Type: Grid-tied system (10 kW solar PV with grid backup).
2. Duration of Use: 2 years.
3. Motivation: Frequent outages and a desire to promote environmental sustainability among students.

Impact:

1. Educational Benefits: Solar power ensured uninterrupted classes, improving academic performance and operational efficiency.
2. Environmental Awareness: The school integrated solar technology into its power supply, raising solar system and environmental awareness among students.
3. Challenges: The initial installation was costly, and the school noted a lack of government subsidies to support such educational initiatives.

Solar power has improved the learning environment at GreenLight Academy, demonstrating the broader societal benefits of renewable energy in the educational sector. The lack of financial incentives for such projects highlights a policy gap.

4.2 Survey Result

4.2.1 Demographic Overview of Respondents

A total of seventeen respondents participated in this survey, providing insights into the adoption and impact of solar power systems across Nigeria. The majority of respondents identified as residential solar system owners, while a smaller portion utilized solar systems for both residential and business purposes. The geographical spread included participants from the South-South, South-West, and North-Central regions of Nigeria. See Figure 1.

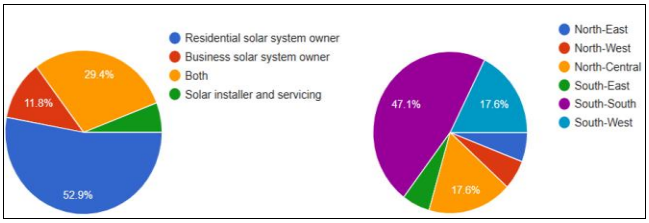

Fig 1: Distribution of Respondents by their Role in Solar System Ownership

4.2.2 Types and Usage of Solar Power Systems

The respondents reported using a variety of solar power systems:

1. Off-grid systems were prevalent among those in rural areas, offering a complete alternative to unreliable grid electricity.
2. Hybrid systems—which combine solar power with grid or generator backups—were commonly used in urban and semi-urban settings, providing flexibility and ensuring power continuity.

In terms of capacity, most systems were either small-scale (less than 5 kW, typically for household use) or medium-scale (5–50 kW, suitable for small businesses).

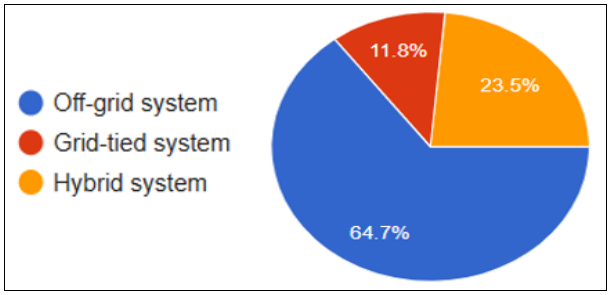

Fig 2: Displays the Types of Solar Power Systems Utilized by Respondents

4.2.3 Motivations for Adopting Solar Power

The primary motivations for adopting solar energy included:

1. High electricity costs: Many respondents were driven by the escalating costs of grid electricity and fuel for generators.
2. Frequent power outages: Respondents noted frequent disruptions in grid power supply as a significant factor.
3. Environmental concerns: A smaller but notable group adopted solar systems due to environmental consciousness and a desire to reduce carbon footprints.

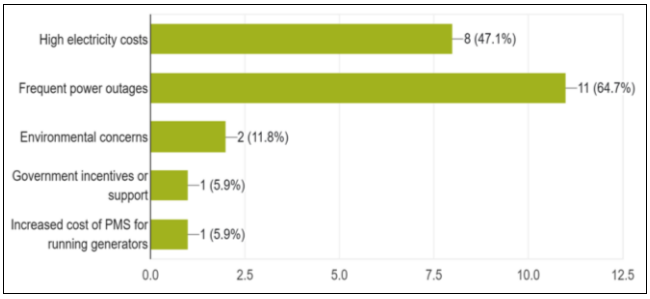

Fig 3: Breakdown of Motivations for Installing Solar Systems

4.2.4 Impact on Power Supply and Reliability

Most respondents indicated that their solar power systems were much more reliable than the national grid. This aligns with the broader literature emphasizing the role of solar energy in improving energy reliability in Nigeria [15].

1. Reliability: Over 70% of respondents reported that solar systems provided consistent electricity supply, reducing their dependence on the unreliable grid.
2. Cost Reduction: While some respondents experienced a significant decrease (over 50%) in electricity costs, others reported no significant change. This discrepancy could be attributed to the high upfront costs of solar installations and maintenance.

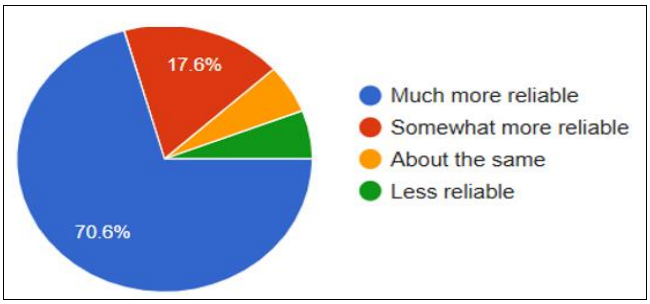

Fig 4: Comparative Analysis of the Perceived Reliability of Solar Systems to Grid

4.2.5 Challenges in Solar System Adoption

Despite the benefits, respondents highlighted several persistent challenges:

1. High Upfront Costs: The initial investment required for solar panels, inverters, and batteries remains a significant barrier.
2. Maintenance and Repairs: Many faced difficulties in sourcing skilled technicians and quality parts.
3. Limited Access to Replacement Parts: Particularly in rural areas, access to affordable, genuine replacement components is limited.
4. Insufficient Power Generation During Rainy/Cloudy Days: Seasonal weather patterns affect solar generation, especially for off-grid systems without adequate storage and Figure 5 summarizes the common challenges faced the solar power users.

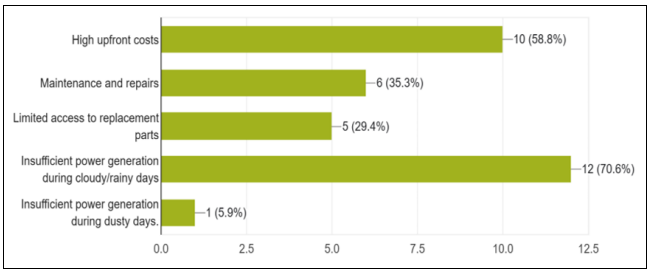

Fig 5: Common Challenges Faced by Solar Power Users

4.2.6 Awareness and Impact of Government Policies

A striking finding was the low awareness of government policies supporting solar power adoption. Even among those aware of the policies like the Solar Power Naija Program, only a few reported that these influenced their decision to install solar systems. This gap suggests a need for more effective communication and outreach regarding available incentives and support for solar energy adoption.

4.2.7 Technological Advancements and Their Impact

Some respondents noted recent technological advancements that improved their solar power systems utilization:

1. Hybrid Inverters: Affordable and efficient hybrid inverters were cited as game-changers in balancing grid and solar power.
2. Maximum Power Point Tracking (MPPT) Technology: Enhanced energy efficiency and better performance, especially during variable weather conditions.
3. Emerging Solar Products: The introduction of new, more efficient solar panels and batteries has improved affordability and accessibility.

These technological advancements align with the literature highlighting the role of innovation in accelerating renewable energy integration [9].

4.2.8 Respondent Recommendations for Improved Solar Adoption

Participants suggested several measures to improve the adoption and reliability of solar power in Nigeria:

1. Government Subsidies and Financial Incentives: Many called for better access to affordable financing options.
2. Improved Regulations and Standards: To tackle the influx of substandard solar products in the market.
3. Public Awareness Campaigns: To educate the population about the benefits and available support for solar adoption.
4. Better Access to Technology and Parts: Respondents emphasized the need for more localized access to quality components and skilled technicians.

The survey results underscore the significant potential of solar energy in addressing Nigeria's persistent energy challenges. While the reliability and environmental benefits of solar systems are evident, financial barriers and policy awareness gaps continue to hinder widespread adoption. These findings align with broader trends in Nigeria's renewable energy landscape, as highlighted in recent studies [10, 11]. The low awareness of supportive government policies indicates a disconnect between policy formulation and on-the-ground implementation. Bridging this gap through targeted outreach and effective policy execution could

catalyze further solar adoption. Technological advancements, such as hybrid inverters and MPPT systems, have made solar power more accessible and efficient. However, the full potential of these technologies can only be realized with parallel improvements in infrastructure, policy support, and public awareness.

4.3 Case Studies of Recent Mini-Grid Projects in Nigeria (2023–2025)

Table 1: Recent Solar Mini-Grid Projects in Nigeria (2023–2025) [12, 15, 16, 17, 18]

Location	Commissioned	Capacity	Partners/Support	Impact/Beneficiaries
Toto Community, Nasarawa State	Nov 2023	352.24 kWp	REA [17], AEDC, PowerGen, World Bank (NEP)	Over 2,000 households, 141 businesses, 45 public institutions – Nigeria's first interconnected hybrid mini-grid
Akipelai & Oloibiri, Bayelsa State	2023	67.32 kWp total	Renewvia [15], REA, World Bank (NEP PBG)	364 households, 170 construction jobs, 7 permanent jobs, lithium-ion battery-based systems
Kilankwa I & II, FCT (Kwali Area Council)	2021 (assessed 2023)	120 kWp (60 each)	REA, World Bank (NEP)	Boosted rural productivity and community development
Bakin Ciyawa & Kwande, Plateau State	Early 2025	550 kWp	REA, Interconnected Mini-Grid Accelerated Scheme (IMAS)	Reliable power for households and small businesses
NEP National Mini-Grid Deployment	2019–2023	103 mini-grids	REA, World Bank (NEP)	Reached MSMEs and public institutions in underserved areas
Nationwide Agreement with WeLight	2025	400 mini-grids + 50 MetroGrids	World Bank, AfDB, WeLight	Targeting 1.5–2 million Nigerians in rural and peri-urban communities
University of Maiduguri & Teaching Hospital	Expected 2025	12 MW	REA, World Bank, AfDB (Energizing Education Programme Phase II)	Provides 24/7 electricity to the university, teaching hospital, and Maiduguri's water treatment plant
University of Abuja	Expected 2025	3.0 MW	REA, World Bank (EEP Phase II)	Reliable power for campus facilities and improved learning environment
Federal University Gashua, Yobe State	Expected 2025	1.5 MW	REA, World Bank (EEP Phase II)	Enhanced academic activities through stable electricity supply
University of Calabar & Teaching Hospital	Expected 2025	7.0 MW	REA, World Bank (EEP Phase II)	Improved healthcare services and academic research capabilities
Nigerian Defence Academy, Kaduna	Expected 2025	2.5 MW	REA, World Bank (EEP Phase II)	Strengthened military training and academic programs
Federal University of Agriculture, Abeokuta	Expected 2025	3.0 MW	REA, World Bank (EEP Phase II)	Boosted agricultural research and student learning experiences
Michael Okpara University of Agriculture, Umudike	Expected 2025	Data not specified	REA, World Bank (EEP Phase II)	Enhanced agricultural studies and campus operations
Modibbo Adama University of Technology, Yola	Expected 2025	5.0 MW	REA, AfDB (EEP Phase III)	Improved technical education and research facilities
Federal University, Dutsin-Ma, Katsina	Expected 2025	1.9 MW	REA, AfDB (EEP Phase III)	Stable power supply for academic and administrative functions
Federal University, Lafia	Expected 2025	1.6 MW	REA, AfDB (EEP Phase III)	Enhanced learning environment and research activities
Federal University, Lokoja	Expected 2025	1.7 MW	REA, AfDB (EEP Phase III)	Reliable electricity for campus development
Federal University of Technology, Owerri	Expected 2025	8.2 MW	REA, AfDB (EEP Phase III)	Advanced engineering education and research capabilities
University of Port Harcourt & Teaching Hospital	Expected 2025	10.7 MW	REA, AfDB (EEP Phase III)	Improved healthcare delivery and academic excellence
University of Uyo	Expected 2025	2.9 MW	REA, AfDB (EEP Phase III)	Stable power for academic and administrative activities
Federal University of Technology, Akure	Expected 2025	4.5 MW	REA, AfDB (EEP Phase III)	Enhanced technological research and student learning
Bayero University, Kano	Commissioned 2019	7.1 MW	REA, FGN (EEP Phase I)	Largest off-grid solar hybrid power plant in Africa, benefiting over 55,000 students and staff
Obafemi Awolowo University, Osun State	Commissioned 2019	Data not specified	REA, FGN (EEP Phase I)	Improved academic activities through reliable power supply
University of Lagos	Commissioned 2019	Data not specified	REA, FGN (EEP Phase I)	Enhanced learning environment with stable electricity
Nnamdi Azikiwe University, Awka	Commissioned 2019	2.0 MW	REA, FGN (EEP Phase I)	Boosted academic research and student learning
Federal University Ndufu-Alike Ikwo	Commissioned 2019	2.8 MW	REA, FGN (EEP Phase I)	Improved educational services through clean energy
Federal University of Petroleum Resources,	Commissioned 2019	0.5 MW	REA, FGN (EEP Phase I)	Enhanced petroleum studies and research capabilities

Effurun				
Usmanu Danfodiyo University, Sokoto	Commissioned 2019	2.0 MW	REA, FGN (EEP Phase I)	Stable power supply for academic and administrative functions
Federal University of Agriculture, Makurdi	Commissioned 2019	4.0 MW	REA, FGN (EEP Phase I)	Boosted agricultural education and research
Abubakar Tafawa Balewa University, Bauchi	Commissioned 2019	0.5 MW	REA, FGN (EEP Phase I)	Improved engineering education through reliable electricity

Table 1 above presents a comprehensive overview of recent solar mini-grid projects across Nigeria from the year 2023 to 2025, with a particular focus on the Energizing Education Programme (EEP). These initiatives, spearheaded by the Rural Electrification Agency (REA) in collaboration with international partners like the World Bank and the African Development Bank (AfDB), aim to provide sustainable and reliable electricity to underserved communities and federal tertiary institutions [12, 13, 14]. The projects encompass a range of capacities and are strategically distributed to enhance educational and socio-economic outcomes nationwide.

4.3.1 Pattern Analysis of Mini-Grid Deployment in Nigeria

Key Partners, and Socio-Economic Impacts based on the mini-grid projects.

Table 2: Analysis of Solar Mini-Grid Projects in Nigeria (2023-2025)

Category	Details
Regional Distribution	Projects are equitably distributed across all 6 geopolitical zones: • North East – 5 universities • North West – 4 universities • North Central – 4 universities + 1 community • South East – 4 universities • South South – 4 universities + 2 communities • South West – 4 universities
Most Active Partners	• **REA (Rural Electrification Agency)** – Lead implementing agency for all projects • **World Bank** – Major financier for NEP and EEP Phase II • **AfDB** – Funded EEP Phase III projects • **WeLight** – Private sector partnership for rural grid-scale deployment
Project Types	• **Institutional Mini-Grids** – Target federal universities and teaching hospitals • **Community Mini-Grids** – Serve rural and peri-urban communities (e.g., Toto, Bayelsa, Plateau) • **Interconnected Hybrid Grids** – New innovation integrating with the national grid
Scale of Deployment	• Over **30 federal institutions** benefitting (academic + healthcare) • **400 mini-grids + 50 MetroGrids** planned under WeLight initiative • National scale includes **103 mini-grids** under NEP
Socio-Economic Impact	• **Education**: Stable electricity for 350,000+ students and 50,000+ academic staff • **Healthcare**: Improved service delivery in teaching hospitals • **Employment**: 170+ construction jobs and dozens of permanent jobs per project • **Sustainability**: Reduced dependence on diesel and carbon emissions
Innovation & Policy	• Interconnected mini-grids (e.g., Toto) • Pay-As-You-Go solar adoption • Legislative reforms (Electricity Act 2023) enable decentralized energy investment

As seen in Table 2, mini-grid deployment shows equitable regional spread, with the North East and South West recording the highest university-level solar adoption.

4.4 Economic and Cost Benefits

Economic benefits include job creation in the solar sector, reduced reliance on imported fuels, and savings from improved energy efficiency. The cost benefits are more evident in off-grid applications, where the cost of maintaining traditional energy infrastructure is high.

5. Conclusion

This study highlights the transformative potential of solar energy systems in addressing Nigeria's persistent power supply challenges. The survey findings confirm that solar power significantly enhances energy reliability and reduces dependence on the national grid, especially in regions plagued by frequent outages. While technological advancements, such as hybrid inverters and MPPT systems, have improved system efficiency and affordability, barriers like high upfront costs, limited maintenance support, and low awareness of government policies continue to hinder widespread adoption. The low awareness and limited impact of government policies such as the Solar Power Naija Program suggest a need for more effective communication, solar energy adoption campaign and policy implementation strategies. Bridging this gap is crucial for accelerating the integration of solar energy into Nigeria's energy mix and achieving national renewable energy targets.

6. Recommendations

Base on the findings of this research, the following recommendations are proposed to improve solar energy integration in Nigeria:

1. **Enhance Financial Support Mechanisms**
    1. Implement government subsidies and low-interest financing options to reduce the upfront costs of solar installations.
    2. Provide tax incentives for both residential and commercial solar adopters.
2. **Strengthen Regulatory Frameworks**
    1. Enforce stricter quality control regulations to

eliminate substandard solar products from the market.
2. Simplify licensing processes for solar power projects to encourage private sector investment.

3. **Expand Public Awareness Campaigns**
   1. Launch nationwide campaigns to educate the public on the benefits of solar power and available government incentives.
   2. Partner with community leaders to promote local solar initiatives and success stories.
4. **Promote Technological Innovation**
   1. Invest in research and development to drive technological innovations tailored to Nigeria's climate and energy needs.
   2. Support the establishment of local manufacturing and assembly plants for solar components to reduce costs and create jobs.
5. **Improve Access to Skilled Technicians and Maintenance Support**
   1. Develop training programs to build technical expertise in solar system installation and maintenance.
   2. Create regional service centers to provide easier access to maintenance and replacement parts.

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