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# REVIEW OF PHOTOVOLTAIC TECHNOLOGY APPLICATIONS AND FUTURE PROSPECTS IN ENERGY SYSTEMS

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**Abstract-** Rising global electric power consumption and its corresponding negative effect on the environment have led to a shift towards cleaner renewable energy sources like solar and wind technology. Nigeria's focus on Photovoltaic (PV) technology ensures a sustainable future, mitigates fossil fuel dependence, and positively impacts the environment. Solar PV technology has been moderately used in Nigeria in areas such as water pumping systems to address energy shortfalls in remote and rural areas, with over 10,000 systems built since 1993, rural PV electrification, residential homes, and small-scale industrial & educational facilities. Nigeria, Africa's largest country, has a large primary energy potential but struggles with electricity generation. Factors contributing to underperformance include weak political will, restricted networks, poor maintenance, insufficient production capacity, conflict disruptions, vandalism, and inconsistent government energy planning. Nigeria aims to diversify its energy mix through renewable technologies like solar PV but faces challenges like affordability, debt, policy insecurity, lack of awareness, and security. This research assesses the possibilities and opportunities of PV technology in Nigeria regarding improving energy security, sustainability, and economic development. This study also compares the current usage of PV in Nigeria, discusses the various challenges requiring additional research, and identifies potential future progress of PV adoption using case studies. Techniques used include analysis of PV scaling data, current technology and trends, and socio-economic challenges. Important conclusions indicate the PV's application in providing rural electricity, promoting policy incentives, stakeholders' involvement, and capacity development.

**Keywords:** Renewable Energy, Photovoltaic Technology, Solar Cell.

## 1. INTRODUCTION

Rising global electricity consumption has prompted a shift towards cleaner technologies like renewable energy comprising solar and wind technology. Solar PV technology provides a reliable, expandable, and cost-effective source of generating electricity. Governments worldwide have created policies to build and operate solar PV systems. There are different varieties of PV materials accessible worldwide, each with its own set of efficiency and drawbacks. The cost of implementing these systems is determined by module attributes and the scope of the project [1].

Nigeria needs renewable electricity especially solar electricity due to its energy problem. According to the World Energy Outlook Report of 2023, Nigeria has not made any significant strides in improving access to electricity. Table 1 shows access to electric power in West African countries, it's evident that a lot needs to be done to improve access [2]. Nigeria benefits from its natural location near the equator in terms of solar resources, especially for off-grid photovoltaic power. However, obstacles like poor market barriers, lack of funding and economic support, lack of political and regulatory support, socio-cultural barriers, inadequate technology for mass production of equipment, and barriers to repair and maintenance services have made integrating solar energy technologies into the grid difficult [3].

Figure 1. Mini solar installation in rural Nigeria [2]

Solar PV technology, notably in water pumping systems, has covered energy shortfalls in remote and rural areas. Figure 1 shows a mini-PV installation in rural Nigeria. By 1993, the World Bank claimed that over 10,000 PV systems had been built, with negligible electrical losses. Thermal, membranes and hybrid systems can be used for home illumination and sea/brackish water

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desalination [4]. Science and technology are critical for national development, enhancing quality of life, creating wealth, and promoting economic progress. In the 1980`s, Nigeria attempted to invest in scientific research but abandoned it owing to hollow talk. Despite President Buhari's vow in 2015 to expand investment, the Tertiary Education Trust Fund says that Nigeria invests only 0.02 Percent of its revenue in this industry [5]. On this premise, it has become a necessity for research institutions, universities, and private companies to be fully involved in driving innovation to enhance research and development for nation-building.

This paper offers the following research contributions by focusing on the application of photovoltaic (PV) technology to the Nigerian context. In this regard, it is differentiated from prior research on the grounds of recent preventive strategies that take into consideration socio-economic that are characteristic of Nigeria's climate. This review will also seek to determine places where PV can make the greatest contribution when it comes to the provision of energy to deserving populations in rural areas and segments of society that are underprivileged.

Table 1. Electricity access in West Africa [2]

| Country | Access to electricity (%) |
|---|---|
| Benin | 41.97 |
| Burkina Faso | 18.95 |
| Cabo Verde | 95.52 |
| Cote d'Ivoire | 71.14 |
| The Gambia | 63.7 |
| Ghana | 86.3 |
| Guinea | 46.81 |
| Guinea-Bissau | 35.76 |
| Liberia | 29.85 |
| Mali | 53.38 |
| Mauritania | 47.7 |
| Niger | 18.6 |
| Nigeria | 59.5 |
| Senegal | 67.98 |
| Sierra Leone | 27.49 |
| Togo | 55.74 |

## 2. PHOTOVOLTAIC TECHNOLOGY OVERVIEW

The PV effect is a process that produces electric power if sunlight crashes into the partition layer of semiconductor substances. It was first identified in 1839 by the French scientist Edmund Becquerel. A lot of research has been done on this topic; solid selenium only shows 1%–2% power efficiency. 1950 saw the creation of crystalline silicon, while 1954 saw Bell Labs produce a silicon photovoltaic cell with a 4% conversion efficiency. With this achievement, a new era in solar energy generation began [6]. When solar radiation impacts a photovoltaic (PV) cell, which is composed of semiconductor materials with a p-n junction, some of the photons are absorbed and produce electron-hole pairs. The voltage differential drives electrons from the junction's n-side to its p-side, resulting in an electric current flowing via the external circuit if one is built. This idea has since changed the way humans use solar radiation to produce power [7].

Current research focuses on achievements in PV systems particularly ideal for areas with high solar intensity and limited economy. For example, the authors in [8] examined the performance of PV systems in areas similar to sub-Saharan regions analyzing the solutions for Nigeria with a focus on the scale and electrification of rural cooperative stores, [9] stressed the prospects of local PV production to make the product more affordable in similar socio-economic setting.

Studies on PV technology including the latest features like bifacial and thin-film modules revealed that efficiency in this study area has been higher compared to regions experiencing similar weather conditions. According to [10], bifacial modules proved to have better energy generation since they could harness energy from different directions of irradiation, especially in the high irradiation area in northern Nigeria.

According to the economic analysis of scientific publications, it has been established that the involvement of developing countries in the implementation of public-private partnerships in PV projects has been enhancing the capacities of those nations. In a similar study, [11] found that investment models targeting low-income households contribute to minimizing the first cost; an obstacle in Nigeria's PV market.

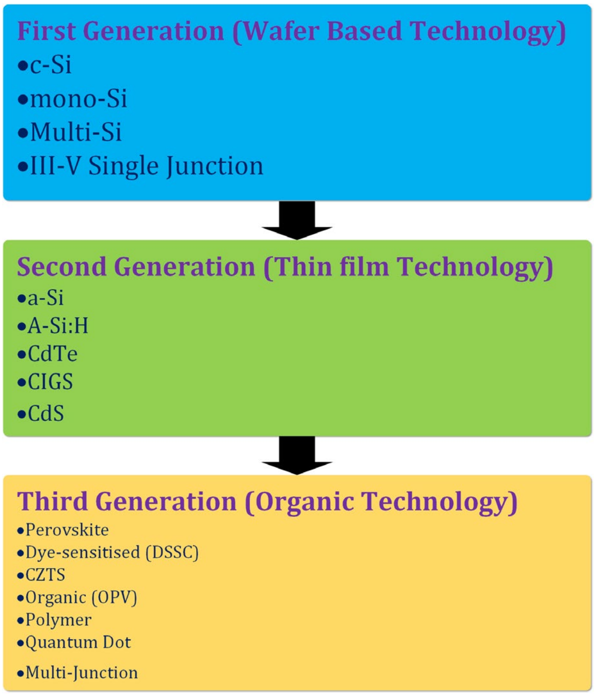


Figure 2. Generation categorization of solar cells [12]

Mono-crystalline silicon cells are single crystals with a continuous internal structure, formed into cylindrical alloys and thinly cut into wafer cells. They are expensive and energy-consuming, but slightly more efficient. Monocrystalline PERC (Passivated Emitter and Rear Cell) cells add layers for increased energy capture and efficiency. Multi-crystalline silicon cells, which are composed of many crystals, have a flaky blue look and require fewer resources for production. They can be manufactured in square ingots and attain efficiency and performance comparable to monocrystalline panels while being significantly less expensive [13]. However, in most places, these panels are more expensive and less efficient than current mono and polysilicon panels. Figure 2a shows the generation categorization of solar cells while Table 2 is a comparative table summarizing the strengths and weaknesses of each PV technology in terms of efficiency, cost, scalability, and maintenance.

Table 2. Strengths and weaknesses of each PV technology

| PV Technology | Efficiency | Cost | Scalability | Maintenance |
|---|---|---|---|---|
| Mono-Crystalline | High | High | Moderate | Low |
| Poly-Crystalline | Moderate | Medium | High | Medium |

### 2.1. Comparative Analysis of Renewable Energy Options in Nigeria

Despite the foregoing, photovoltaic (PV) technology is a promising bet for Nigeria's future energy needs, alongside other renewable energy sources, including biomass and hydroelectric power. A comparison is made to determine the disparity in energy generation efficiency, flexibility, and cost of these technologies.

Table 3 shows quantitative data comparing energy production per kWh, scalability potential, and initial cost for PV, biomass, and hydroelectric power in Nigeria. This comparison shows how PV is scalable while offering cost savings over time although initial investment cost in PV is higher than in biomass options.

Table 3. Comparative analysis

| Energy Source | Energy output (kWh\yr) | Scalability | Initial Cost ($/kW) |
|---|---|---|---|
| Photovoltaic | 1,500 - 1,700 | High | 1,000 - 1,500 |
| Biomass | 1,200 - 1,300 | Moderate | 500 - 800 |
| Hydroelectric | 2,000 - 2,200 | Low | 3,000 - 4,500 |

Table 3 offers a better understanding of the values that PV dispatch can offer compared to more conventional dispatch types which are important in rural or off-grid locations where scalability and maintenance costs are important factors [1].

## 3. TECHNOLOGICAL INNOVATIONS AND RESEARCH

Photovoltaic (PV) technological breakthroughs have altered solar energy generation, making it more efficient, economical, and accessible. New PV technologies like perovskite, tandem, and organic solar cells offer promising advantages, but efficiency, stability, and scalability remain issues. Innovative manufacturing techniques like roll-to-roll printing and thin-film deposition have helped solar panel scalability and cost reduction. The use of energy storage technology like batteries and advanced energy management systems has increased grid integration and reliability [14]. The highest-wattage PV module currently available is the 720/750 W module designed by Huasun Solar in China.

Increased solar energy absorption through the use of solar tracking systems and concentrator technology leads to increased energy output and efficiency. Reducing the environmental impact of PV systems is the goal of environmental concerns like recycling and using eco-friendly components. Policies and economic factors play a crucial role in promoting the widespread application of solar photovoltaic technology. There are still challenges in boosting grid integration, cutting costs, and enhancing stability. Future studies and projections indicate that photovoltaic technology will advance further, opening the door to a clean and renewable energy future [14].

## 4. METHODOLOGY

This section overviews the approach used in this work to scan and assess various PV technology developments and their utility in Nigeria's energy context.

### R.2 4.1 Methodology Framework and Data Collection Process

This research used secondary data whereby articles from peer-reviewed journals, government energy reports, and industry case studies were collected through an extensive multistage process. First, we looked at other PV technologies that may be appropriate for the Nigerian climate, in terms of efficiency, cost, and performance. Third, data analysis involved a comparative analysis of these technologies we evaluated them on energy yield, scale, and economy. The methodology involves three key phases:

1. Data Collection: The literature review collected information from research and energy articles and reports from February 2018 to June 2023.
2. Analysis Framework: We used a comparative method to compare the energy production rates, the cost efficiency, and the overall ways of implementing them.
3. Evaluation: Last but not least, data was analyzed with the view to establishing the cost-effectiveness of PV systems against other sources of renewable energy in Nigeria.

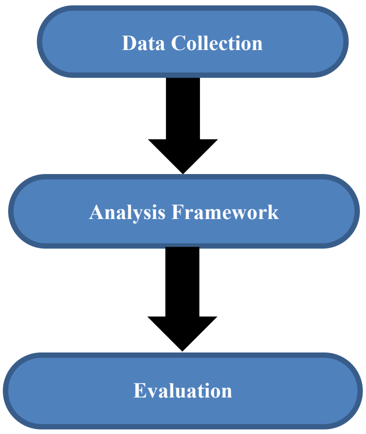


Figure 3. Framework outline

The outlined framework is displayed graphically in Figure 3 showing the process and sequence of data gathering and analysis for this investigation [7].

## 5. SOLAR ENERGY POTENTIAL IN NIGERIA

Nigeria's average solar radiation illustrated by Figure 4 is 12.6 MJ/m$^2$ at its southern coast and 25.2 MJ/m$^2$ in its far north. This is comparable to 229.1667 W/m$^2$ of power. Direct normal irradiance over Nigeria averages 724 kWh/m2 in the deep south and 1653 Wh/m$^2$ in the extreme north, according to the Global Solar Atlas (2021). With a total surface area of 923,786 km$^2$, Nigeria receives 1500 x 109 MWh of solar radiation annually, averaging 19 MJ m-2 day-1. [15]. The weather conditions in Nigeria are highly conducive for photovoltaic (PV) applications throughout the year. The northern region of Nigeria offers optimal climatic conditions for solar applications. The global horizontal irradiation map of Nigeria indicates that the daily irradiation ranges from 4.2 to 6.2 kWh/m$^2$, whereas the yearly irradiation ranges from 1534 to 2264 kWh/m$^2$.

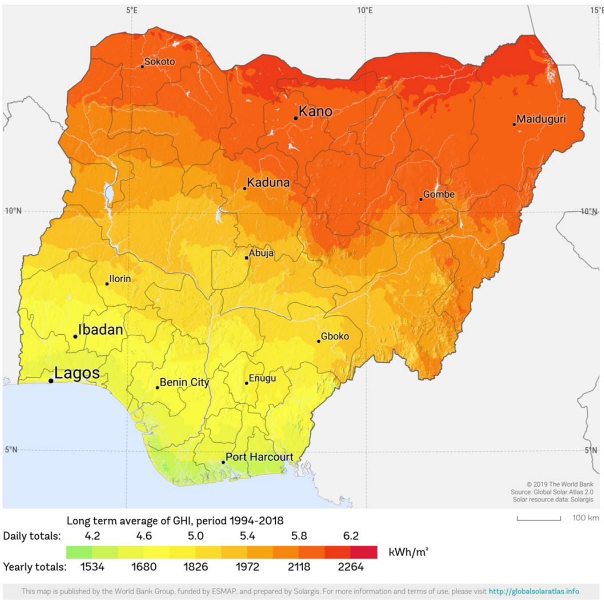


Figure 4. Solar irradiation map of Nigeria [26]

The mean monthly values are presented in Table 4. Multiple papers have demonstrated the potential of photovoltaic (PV) applications by examining current PV installations and making estimates for future installations. The largest photovoltaic (PV) project at present is a 10 MW power plant situated in Kumbotso. Additionally, there are 3.5 MW plants located in Makurdi and Kano, as well as 2.35 MW and 2 MW plants located in Ijebu Mushin and Awka, respectively. Numerous rooftop photovoltaic (PV) installations are distributed throughout country. [16].

The frequency distribution and coefficient of variation throughout Nigeria's five main climate zones were studied by the authors in [17]. The data indicate that gross irradiation inside the modal radiation category of 15.01-20.01 MJ/m$^2$/day occurs on 46.88% and 40.6% of days in tropical and mangrove swamp forests, respectively, whereas 46.19%, 55.84%, and 58.53% of days in savannahs in Guinea, Sahel, and Sudan. The coefficient of variation is low from January to December, high from July to August, and February to December in tropical rainforests, Guinea savannah, and mangrove swamp forests respectively.

The study found that the northern horn, which has a steady drop in surface receipt downstream, has the highest global sun irradiance and clearness index. The sunlight being received across Nigeria, as well as the irradiance, makes it an ideal place for solar PV-driven energy generation. The PV generation systems can utilize these parameters in abundance to ensure a steady supply of power in the country, which in turn reduces over-reliance on fossil fuel energy sources, thereby, reducing environmental degradation.

## 6. PHOTOVOLTAIC APPLICATIONS IN NIGERIA

Nigeria, Africa's most populous country, has a large primary energy potential but struggles with electricity generation. Over 20 years, Nigeria's growth rate is 93%, with a 45% electrification rate. Factors contributing to underperformance include weak political will, restricted transmission and distribution networks, poor maintenance culture, insufficient production capacity, conflict disruptions, vandalism, and inconsistent government energy planning. Nigeria seeks to diversify its energy mix, addressing environmental impact and insecurity through renewable technologies like solar PV. Research on PV rural electrification in Sub-Saharan Africa shows affordability and appropriateness, but high costs due to import components persist. Nigeria's 2014 PV panel plant in Karshi may reduce costs and make solar electrification more competitive for rural residents [18].

Table 4. Average monthly solar insolation [11]

| Month | GlobHor kWh/m$^2$ |
|---|---|
| Jan | 177.9 |
| Feb | 165.5 |
| Mar | 186.3 |
| April | 173.4 |
| May | 168.3 |
| June | 147.6 |
| July | 137.6 |
| Aug | 132.1 |
| Sept | 136.5 |
| Oct | 158.7 |
| Nov | 171.6 |
| Dec | 175.8 |

A survey of 150 residential structures in Akure found low adoption of solar PV systems, with most relying on diesel/petrol generators. High costs and lack of understanding hinder solar PV's growth. Governments must provide incentives and support to help the market grow [19-20]. Nigeria's solar energy potential is limited to 28 MW as of 2019, juxtaposed to compared to 3,061 MW for South Africa, due to transmission and distribution bottlenecks. The ten most sizeable PV facilities in Nigeria include the Federal University of Agriculture, Makurdi with a capacity of 3.5 MW, Bayero University, Kano with a capacity of 3.5 MW, Tulip Cocoa Processing Ltd. in Ijebu Mushin with a capacity of 2.35 MW, Nnamdi

Azikiwe University in Awka with a capacity of 2 MW, Usmanu Danfodiyo University in Sokoto with a capacity of 2 MW, the Federal Ministry of Power, Works, and Housing (FMPWH) Secretariat in Abuja with a capacity of 1.52 MW, the Usman Dam Water Treatment Plant in Abuja with a capacity of 1.2 MW, Alex Ekwueme Federal University in Ndufu Alike-Ikwo with a capacity of 1.155 MW, Nigerian Breweries Plc. in Ibadan with a capacity of 0.663 MW, and Jabi Lake Mall in Abuja with a capacity of 0.610 MW.

### 6.1. Case Studies of PV Applications in Nigeria

This section offers a real picture of current PV projects in Nigeria and their realistic implications and realities. These examples give an insight into how PV technology can respond to the challenge of energy for sustainability.

#### 6.1.1. Case Study 1: Kumbotso 10 MW Solar power Project

Case Study Summary: The Kumbotso 10 MW solar PV power plant established is in Kano State and is among the large-scale power stations in Nigeria. Started under the Nigerian government's renewable energy investment plan, the plant was expected to help supplement inadequate power supplies in Kano and other regions. This particular installation can produce approximately 10 MW of power, enough to supply many homes and operational establishments. It has satisfied important concerns, including energy deficiency, supporting the local economy, and avoiding over-dependence on diesel generators [21].

Challenges

Maintenance: Technical support of the PV systems is needed frequently and this has been a problem in the rural regions of Kano.

Environmental Factors: Generally, dust on the panels and high temperatures of the panels reduce the efficiency of the PV and thus require more frequent cleaning.

Impact

Employment: The project, therefore, generated employment during the construction as well as during its functioning.

Economic Boost: Since the PV plant is a viable source of electric power for diesel generators, the fuel costs have been lowered and a sustainable economic setting has been created.

#### 6.1.2. Case Study 2: Federal University of Agriculture, Makurdi 3.5 MW Solar Power Plant

Case Study Summary: The Federal University of Agriculture, Makurdi has a 3.5 MW solar power plant, which is an educational facility as well as renewable energy capable of use throughout the University. Following the conduct of the project in response to the many recurrent disturbances in grid power, energy security at the university has enormously been enhanced, and the danger of dependency on the national grid has almost been eradicated. The electricity produced by the PV installation is used at the campus facilities such as offices and research stations [15].

Challenges

Technical Expertise: This has occasionally presented operational challenges because there are few people available with the skills required for the delicate and technical work of maintenance.

Funding: This led to problems in acquiring enough finances to support the project at the university and thus the work was done slowly.

Impact

Educational Benefits: The spirited plant also acts as a practical training facility for students doing renewable energy and electrical engineering.

Energy Savings: Here the authors noted that the conservation of fossil resources has led to reduced operating costs and environmental pollution.

The following two cases demonstrate that PV technology is both feasible and effective in Nigeria, but it also provides an understanding of some of the key issues affecting its maintenance, financing, as well as the availability of a skilled workforce. Subsequent specific PV projects in Nigeria might be improved through solving these challenges to maximize its sustainability and economic effects.

## 7. DATA PRESENTATION AND ANALYSIS

This section provides information concerning the PV energy production in Nigeria and distribution of PV projects across a region as well as investment in renewable energy. To increase understanding and make comparisons, the use of tables bars, and pie charts is done. These representations emphasize different regions in Nigeria where PV has been beneficial, especially Northern regions with the highest Solar ratio.

Table 4 displays PV energy production rates in major Nigerian regions. Data reflects differences in solar potential and the extent of PV infrastructure investments in each area, emphasizing the significant PV opportunities in northern Nigeria.

Table 5. Regional PV energy production in Nigeria (IEA, 2023)

| Region | PV Energy Production (MWh/yr) | Investment ($ million) | Number of PV Projects |
|---|---|---|---|
| Northern | 12,500 | 35 | 15 |
| Southern | 8,000 | 20 | 8 |
| Eastern | 5,500 | 10 | 5 |
| Western | 6,200 | 12 | 6 |

The regions of Nigeria and the corresponding PV energy production are presented in Figure 3 featuring regions with the greatest potential and established PV installations. Specifically, Northern Nigeria is more dominant in energy production because of high irradiance levels and large-scale PV project investment.

Figures 5 and 6 show the distribution of PV investments across Nigerian regions. This visual demonstrates the financial commitment to PV technology in high-potential areas, with the Northern region receiving the largest share due to its optimal solar conditions.

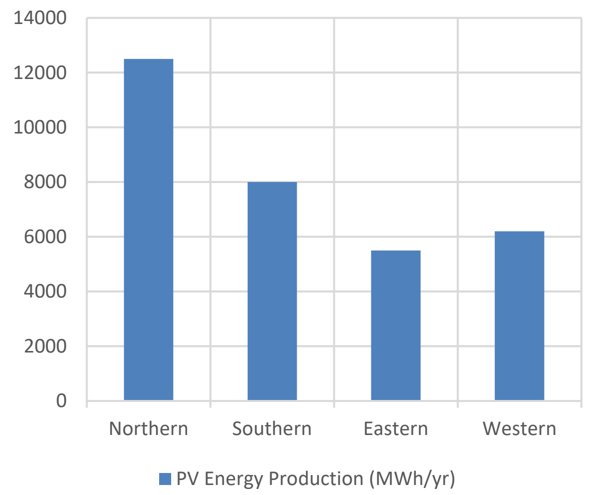


Figure 5. PV energy production by region

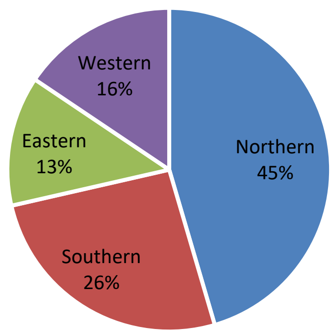


Figure 6. PV Investment Distribution

### 7.1. PV Data and Nigeria's Energy Mix

This evidence depicts considerable gaps in tangible PV generation and funding emission by Nigerian geographical areas. With regard to irradiance, the Northern region is the most suitable for PV projects. But Southern and Western areas seem to have the prospects for expansion with more capital. Based on this analysis, adding more PV systems to lower-performing areas can Increase Nigeria's energy security.

## 8. CHALLENGES

Nigeria is confronted with various challenges when it comes to PV technology. Nigeria's PV has specific socio-economic and policy peculiarities, including volatile subsidy programs, long procedures, and unpredictable regulation of PV equipment importation. For example, this has been evidenced by unpredictability in subsidies making long-term investment in PV unviable. Further, the global PV deployment risks are still higher due in part to security issues in some parts of the region than in other similar developing countries [22]. Numerous studies have been conducted to determine the environmental benefits of PV, and there is powerful evidence of its long-term economic gains as well. Lifetime costs: Contrary to fossil fuel systems, the costs of PV systems are low during their use. The cost of installation while initially expensive, PV offers low maintenance costs and the ability to minimize bills for electricity in households and commercial buildings in Nigeria.

Comparative economic studies show that energy from PV is fairly expensive at $0.26-$0.50 per kilowatt hour while diesel generation came to $0.50 per kilowatt hour. The above difference supports the rationale for PV at an economic level especially in areas that require high energy usage [15].

While PV has lucrative opportunities, its implementation in Nigeria is burdensome by various challenges including high initial costs, later expenses, and unstable policies. These involve the kind that comes with subsidies from the government, policies that support the local manufacturing of photovoltaics, and community funding.

Implementation of new policies starting from 2022 Nigerian Renewable Energy and Energy Efficiency Policy try to offer more favorable rules on approval processes and PV import tariffs, which may lead to better market entry [7].

Many Nigerians find setting up solar energy systems challenging due to the country's limited electrical access and low income. Investors are concerned about the oil sector's illiquidity and losses. The Central Bank of Nigeria strives to reform debt regulations to avoid bankruptcy. As the country faces dangers from terrorists, kidnappers, rebels, militants, and bandits, security is critical for renewable energy penetration [15].

Furthermore, the lack of access to modern energy services hinders socioeconomic development in rural areas. Limited energy supply restricts the use of appliances and technologies that can improve productivity, income generation, and overall living standards. It also affects access to communication services, such as mobile phone charging and internet connectivity.

- Initial Capital Cost: Stand-alone and hybrid systems often require high upfront capital investments. Nonetheless, various financing mechanisms, such as microfinance, public-private partnerships, and community-based funding, can help overcome this challenge [21].
- Maintenance and Operation: Ensuring technical expertise, regular maintenance, and proper operation are critical for the sustainable and reliable operation of stand-alone and hybrid energy systems. Capacity-building programs and local training initiatives can address this challenge [22].
- Battery Technology: Battery technology has seen improvements with the rise of lithium-ion batteries. These batteries boast energy density, life spans, and better efficiency compared to traditional lead acid ones. Ongoing research aims to improve battery efficiency and investigate materials like solid-state batteries and flow batteries [20].
- Grid-Scale Energy Storage: When it comes to grid-scale energy storage solutions are gaining traction to address the

nature of energy sources. Technologies like enhanced flow batteries, and CAES (compressed air energy storage). Pumped hydro storage permits surplus energy to be stored and released when needed most. These technologies play a role, in enhancing the reliability and resilience of the energy system by offering stability and balancing services for the grid [22].

- Smart Grids: Smart grids have become a choice, for managing energy. By incorporating automation, control, and communication technologies, into the electrical system smart grids allow for efficient monitoring, optimization, and control of energy production, distribution, and usage. They enhance the resilience of power infrastructure support the integration of energy sources and empower users to participate in energy management through real-time data analysis.
- Demand Response Programs: These programs encourage customers to adjust their electricity usage during times of demand or limited supply. Customers have the opportunity to receive rewards and contribute to grid stability by reducing their energy consumption during demand periods. Such initiatives are often complemented Most often, these programs utilize one or another smart grid technologies that enable highly automated and precise control over energy consumption depending on the grid's conditions.
- Energy Storage in EVs: High EV replication and usage rates are creating an opportunity for energy storage and energy management. Using vehicle-to-grid V2G, EVs can not only receive energy from the grid but also send it back when the resource is needed. This bidirectional flow can be effective in grid balancing, peak load shedding, and using renewable energy resources to their full extent. [22].
- Technical Challenges: Renewable energy sources, comprising solar and wind, are erratic and unpredictable, which presents technological difficulties for grid stability and integration. The problem is made worse by the inadequate infrastructure for energy storage [24].

## 9. FUTURE PROSPECTS

Nigeria currently has a significant, demonstrable market potential for PV systems that producers and marketers from around the world may capitalize on. Its future is dependent on its utilization, development, and harnessing. PV power has the potential to enhance the living conditions of common people across the country [25]. PV research, development, and demonstration activities have previously been successful on a small scale. However, future research should endeavor to present inventions that increase the efficiency of PV and are available in highly irradiated countries like Nigeria.

Possible research areas are PV interconnection with other renewable power sources, improvement of power conversion in hot climates, and incorporation of local materials for system fabrication to minimize cost. This means that when specific modalities for high-sunshine countries like Nigeria are focused on the energy sector can be greatly enhanced especially through discouraging energy losses and advocating high-efficiency technology [27]. The government may take the lead by enacting advantageous policies, demonstrating actual commitment, and raising public understanding of PV's potential [25].

Nigeria has huge prospects for CSP (concentrated solar power) and photovoltaic generation of 427,000 megawatts, which is six times the average electricity consumption in France. Nigerians already pay 3.5 trillion naira per year on diesel and PMS-powered generators, making solar energy more affordable. In Nigeria, the average cost per unit of energy generated by generators is \$0.50kWh, whereas renewable energy is \$0.26-0.50kWh. Because of insufficient electricity supply and strong demand, the demand-side boom for solar energy in Nigeria looks promising [26].

## 10. CONCLUSIONS

Nigeria is greatly endowed with solar-related resources required to thrive in terms of photovoltaic technology and its applications but still lags juxtaposed to its contemporaries on the continent, from the viewpoint of PV penetration in Africa. This work reviewed solar photovoltaic technology, applications, and challenges hindering massive penetration of this system in Nigeria to improve electricity accessibility. Undoubtedly, the small number of mini and large-scale grid-tied PV installations are functioning optimally thus it affirms the notion of Nigeria having a suitable climate for PV installations.

However, because of challenges such as financing, lack of government policies and subsidies, etc., electricity generation and penetration are still below standards. Nonetheless, it is still possible for Nigeria to use solar photovoltaic technology to solve its electricity requirement, improve environmental issues, and bring about economic prosperity. This paper has demonstrated the suitability of PV technology as a source of clean energy in fulfilling Nigeria's energy mix and its commitment as a platform for analyzing Nigeria's energy and environmental problems.

It is understood that getting the PV system installed in the first place is a little expensive, that being said, the end costs are considerably low in comparison to the diesel or petrol-generated setup. In addition, PV also contributes to the reduction of carbon emission targets in Nigeria hence satisfying the global demand. On this basis, PV technology is marketed not only as an environmental solution for electric power but also as an economic opportunity for the enhancement of immunity to high fuel costs and deterioration of the environment. From a research perspective, more significant work needs to be produced on the optimization of PV manufacturing on current infrastructure, regional manufacturing, and funding. These advancements will guarantee that PV structures are usually ready to provide massively to Nigeria's economic growth, energy security, ecological conservation, and protection. These sorts of initiatives could assist Nigeria in attaining its renewable energy targets while encouraging a cleaner power future.

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