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**SOLAR ENERGY AS A POTENTIAL SOLUTION TO
ELECTRICITY SECURITY IN NIGERIA**

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ABSTRACT

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<p>The study examines the possibilities and potential of solar energy for the public sector in Nigeria. Energy access is critical to Nigeria's efforts to reduce poverty and grow its economy. Nigeria is facing severe energy scarcity as a result of growing energy consumption. Paradoxically, the country has abundant renewable energy resources. The potential of solar energy to supply Nigeria with sustainable power is examined in this study. An increasingly trustworthy alternative source of power generation is photovoltaic solar energy. Utilizing solar energy to meet home energy needs and the needs of rural areas while also providing the industrial sector with grid-supplied electricity can help the country's economy. Therefore, it is essential that the government and other key players in the energy sector create policies and cultivate an environment that will promote the use of photovoltaic technology and solar energy generation. Few players in the public and business sectors are aware of the potential benefits of solar energy and related technologies. The market is warped as a result of this ignorance and lack of information, which increases the perceived risk of possible renewable energy projects. Informing the public about the availability, benefits, and opportunities of solar energy resources is essential to raising public awareness and igniting interest in the energy sector.</p>		

Keywords:

Electricity, Nigeria, renewable energy, solar energy

CONCEPT DEFINITION

AC

Alternative current

DC

Direct current

CREN

Council for Renewable Energy Nigeria

ECN

Energy Commission of Nigeria

GDP

Gross domestic product

GHG

Greenhouse gas

IEA

International Energy Agency

NEPZA

National Export Processing Zones Authority

PV

Photovoltaic

SESN

Solar Energy Society of Nigeria

ABSTRACT

CONCEPT DEFINITION

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1 INTRODUCTION

Any country's ability to eradicate poverty, advance economically, and ensure its security depends mainly on its access to energy. These days, it is essential for every country to have a reliable supply of energy. The long-term supply of reasonably priced, conveniently accessible, and environmentally friendly energy sources is crucial for future economic growth. For most developing nations, having access to secure and consistent energy is still a pipe dream. This shortfall is problematic for their ability to advance economically, socially, and agriculturally and raise their standard of living. As a result, a sustainable energy source is needed. Making the switch to renewable energy sources—such as hydropower, wind, and solar—offers the potential to reduce greenhouse gas (GHG) emissions, alleviate energy poverty, and foster local economic growth. In addition to improving energy availability, sustainable energy projects foster social justice and resilience. (Jacobson & Kammen, 2007, 798-801.)

Sustainable energy is described as energy that satisfies economic, social, and environmental needs within society's more prominent social development context while also considering fair distribution (Davidson, 2006, 14-25). However, to mobilize energy resources for development, sustainable energy will need new strategies. This would mean moving to renewable energy sources, developing and sharing technology for renewable and sustainable energy, optimizing energy conservation and efficiency, and developing technological innovations that enable using fossil fuels more cleanly (Tsighe, 2001, 14–25). Therefore, because of the fast-increasing demand and the evolving characteristics of the economy, Nigeria has an inadequate supply of usable energy. Paradoxically, the country has abundant renewable energy resources.

Nigeria is endowed with an abundance of renewable and conventional energy resources, including biomass, hydro, solar, and wind power, all of which can be used to meet the demands of the country's people and export excess energy to neighboring countries as a marketable good in order to generate revenue. Nigeria's power situation and possibilities for renewable energy are depicted in figure 1 below. But because of the nation's continuous population expansion, the domestic supply is now inadequate and unable to meet the demand.

Thus, an immediate response is required before things go out of control. This insufficient supply has several consequences. Nigeria still faces severe energy shortages even after spending billions of dollars over the previous 20 years to enhance and expand the nation's energy supply using traditional energy sources. (Usman, Abbasoglu, Ersoy & Fahrioglu, 2015, 429-437.)

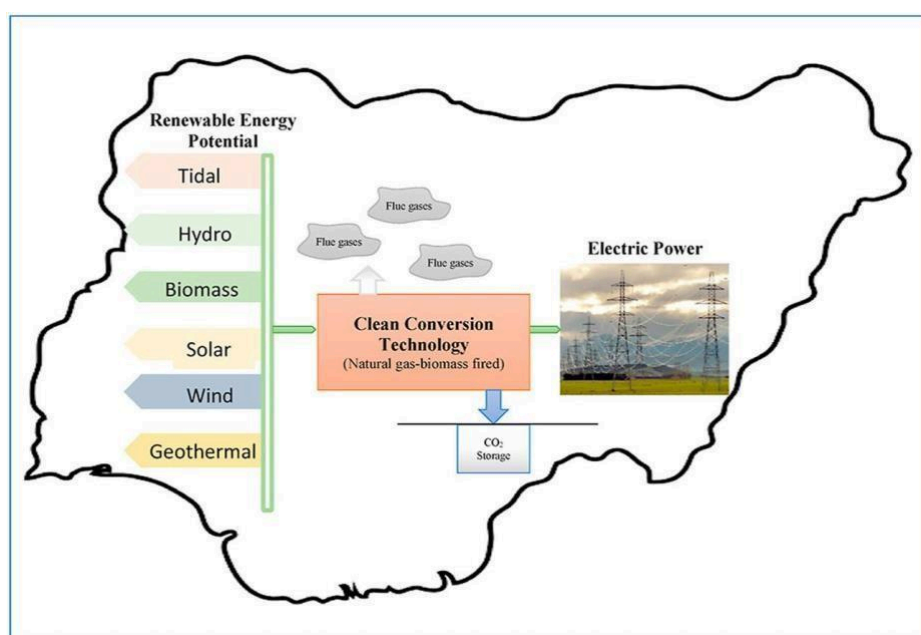


FIGURE 1. Nigeria's energy situation and potential for renewable energy (adapted from Owebor, Diemuodeke, Briggs & Imran, 2021, 773-798).

However, renewable energy can help reduce poverty directly because it provides a significant portion of the energy needed to start businesses and create jobs. This is especially true for rural communities that are not yet connected to the national grid, as numerous renewable energy projects in various countries have shown unquestionably (Federal Ministry of Environment, 2013). A number of renewable energy methods provide energy for vehicles, space heating, cooking, and lighting. With solar energy as the cornerstone for other renewable energy sources, energy efficiency, conservation, and renewable energy resources at its disposal, Nigeria ought to be able to meet any future growth in demand without having to rely more on non-renewable resources. The study focuses on solar energy as a workable solution for Nigeria's electrical security. The study looks at the state of solar energy in Nigeria today and in the future, as well as the different issues that the country faces when it comes to installing, acquiring, and growing solar energy. Additionally, the study examines how adopting solar energy affects electricity security in Nigeria.

In every country, energy has been an essential part of every economic sector. Because of the fast-increasing demand and the evolving characteristics of the economy, Nigeria has an inadequate supply of usable energy. Nigeria, a tropical country, enjoys abundant sunshine that may be converted into many energy sources to give the nation sustainable power. This study assesses Nigeria's solar energy prospects and existing conditions. Furthermore, the study examines the different challenges associated with solar energy production, installation, and purchase. It also examines how solar power would contribute to Nigeria's sustainable energy movement.

Nigeria as the study area, is a country in West Africa with 923,768 square kilometers, is bordered by latitudes between 4° and 14° and longitudes between 3° and 14° (Nigeria Embassy 2013). The total solar radiation received by its 923,768 km² of land varies from approximately 3.5 kWh/m²/day in the coastal region to approximately 7.0 kWh/m²/day in the far north on an annual average basis (ECN 2003; ECN-UNDP, 2005). Nigeria has an average of six hours of sunshine daily and 19.8 MJm²/day of equally distributed solar energy (Newsom, 2012). In contrast to the tropical climate in the south, the country's northern area is characterized by a savanna environment, with semi-arid or desert terrain in the far north. Nigeria is a popular target for solar energy due to the nation's ongoing electricity needs and ample sunshine (Villegas, 2018). Figure 2 below shows how sun irradiation is distributed over Nigeria. Despite its lack of power generation, Nigeria is ideally located to use the enormous potential for solar energy sources to sustainably satisfy all of its electrical needs.

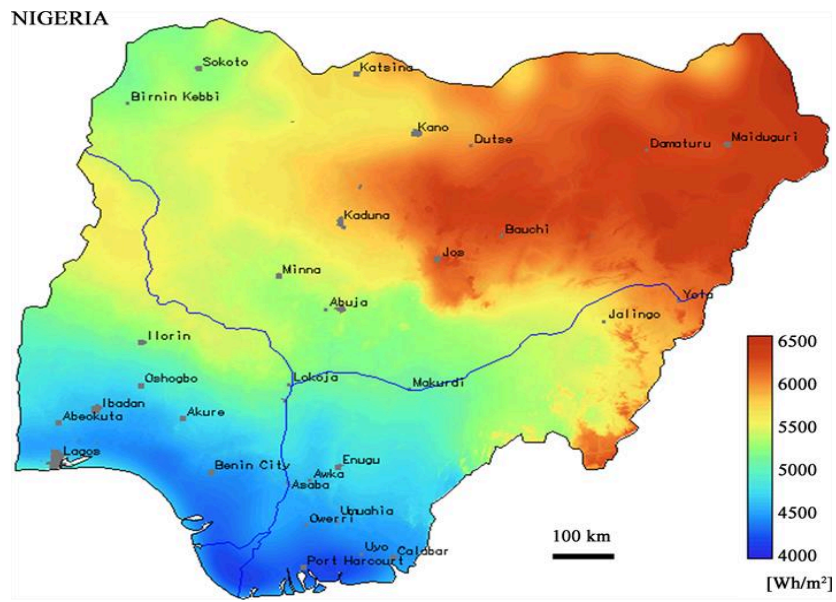


FIGURE 2. Nigeria solar irradiation distribution (adapted from NACOP, 2016).

2 ELECTRICITY SECURITY: THE NEEDS AND CHALLENGES OF NIGERIA

The desire for a better quality of life and population increase are the primary drivers of the rising demand for energy generation. In the past, using fossil fuels to generate electricity had no negative repercussions; now, with the acceptance of climate change, numerous concerns have been raised (Ayodele, Olanrewaju & Jimoh 2012, 84-97). By 2030, it is intended to provide 80% of the population with increased access to power. However, considering that Nigeria still produces insufficient amounts, it is unclear how people would always have access to it. In Nigeria, energy that might typically come from renewable sources is produced using coal and oil. In rural areas, most people use charcoal to cook; there are times when the sun is the only source of light. The Nigerian Energy Commission reports that the country's residents spend an astonishing \$22 billion annually—nearly 5% of GDP—on oil to run their generators (Rural Electrification Agency, 2019.) Nigeria has made many attempts throughout the years to attain electricity security (Anumaka 2012; Oseni 2012). Nigeria still faces severe energy shortages even after spending billions of dollars over the previous 20 years to strengthen and expand the nation's energy supply (Usman et al., 2015, 429–437). There is an enormous disparity between the supply and demand for energy as a result of these factors as well as the restricted local production, necessitating a clean energy source for everyone. Therefore, in order to find viable answers, it is imperative that continued research be done on the energy issue.

However, in order to help developing countries like Nigeria accomplish Sustainable Development Goal 7, photovoltaic energy is the most appropriate clean energy alternative because of its advantages for the environment and the economy. The Paris Climate Agreement and the 2030 Agenda for Sustainable Development both include energy as a central theme, according to Sustainable Development Goal 7. If everyone has access to affordable, reliable, sustainable, and modern energy by 2030, then billions of people will be opening up new avenues for economic growth and employment, empowering women, children, and youth, improving health and education, creating more equitable, sustainable, and inclusive communities, and strengthening their ability to withstand and adapt to climate change. (HLPF, 2018.)

Sunlight, or solar energy, is the most readily available energy source on Earth. The solar cell gathers and transforms the massive amounts of energy that the sun emits into space daily into electrical power. The phenomenon known as photovoltaics, which allowed sunlight to be converted into energy, was discovered in 1839 (Sustainableenergyz, 2012). Before the invention of the solar cell, which occurred more than a century later, this energy source was useless. Today's solar chargers are more efficient than ever, thanks to improvements in design innovation. Solar panels were mainly used aboard spacecraft in the mid-1950s. In the 1970s, when solar calculators first gained popularity, most people were likely unaware of solar power. Because of its many benefits, solar energy is currently employed to power innumerable houses and large buildings, including the provision of a solution that is affordable, link-free, advantageous, and eco-friendly (Adedeji, Deveci, Salman & Abiola, 2023, 1-15.)

2.1 Nigeria's Potential for Solar Energy-Based Electrical Energy Generation

Since solar energy is non-renewable and emits no pollutants, it presents a great potential solution for generating clean electricity. Despite the vast amounts of solar energy that impact the surface of the planet, many underdeveloped countries, including Nigeria, require assistance in making use of the resources. Investing in solar energy harvesting devices can assist in reducing greenhouse gas emissions (GHG) and ending energy poverty. (Mohammed, Mustafa, Bashir & Ibrahim 2017, 820-838.) Photovoltaic technology, sometimes known as solar photovoltaics, is a popular way of converting solar energy. The photovoltaic effect is used in this technique to transform sunlight into electricity. Photovoltaic materials, such as crystalline silicon or thin-film semiconductors, absorb photons when exposed to solar radiation. Photons excite electrons in the substance, forcing them to flow and generate an electric current. Conductive wires then catch this current, producing direct current (DC). Bell Labs created the first viable solar cell in 1954, kicking off the photovoltaic revolution in energy production (Green, Emery, Hishikawa, Warta, & Dunlop, 2017, 3-13.) These days, photovoltaic systems are a vital component of international initiatives to harness renewable energy sources for various purposes, from powering residential buildings to massive solar power plants.

The photoelectric effect allows solar cells (photovoltaics) to convert sunlight into electricity. The photoelectric effect describes how electricity moves when light strikes a substance. The electrons in the substance's molecules receive energy from the light, allowing them to travel and generate a current. The solar panel has three layers: silicone, phosphorus, and boron. The lower layer is built with "positive type" silicon, which generates a positive charge. (Adedeji, Deveci & Salman, 2022.) The top layer comprises "negative type" silicon, emitting negatively charged electrons. A connecting layer, also known as an intermediary component, acts as an insulator between negative and positive silicon layers. When sunlight's photons, or energy particles, strike the top layer of a solar cell, they are absorbed, and a current begins to flow. When photons impact negative-type silicon atoms, they take electrically charged electrons from their "parent" particles, producing this current. The positively charged protons in the p-type silicon layer of the solar cell attract electrons, which travel via wires to a battery and are stored before being released back into the solar cells. Instead of a single solar cell, a panel of solar cells can produce enough electricity to power an entire building. Figure 3 shows a solar hybrid power plant, whereas figure 4 shows solar energy in operation.



FIGURE 3. A solar hybrid power plant (adapted from Rural Electrification Agency, 2019)

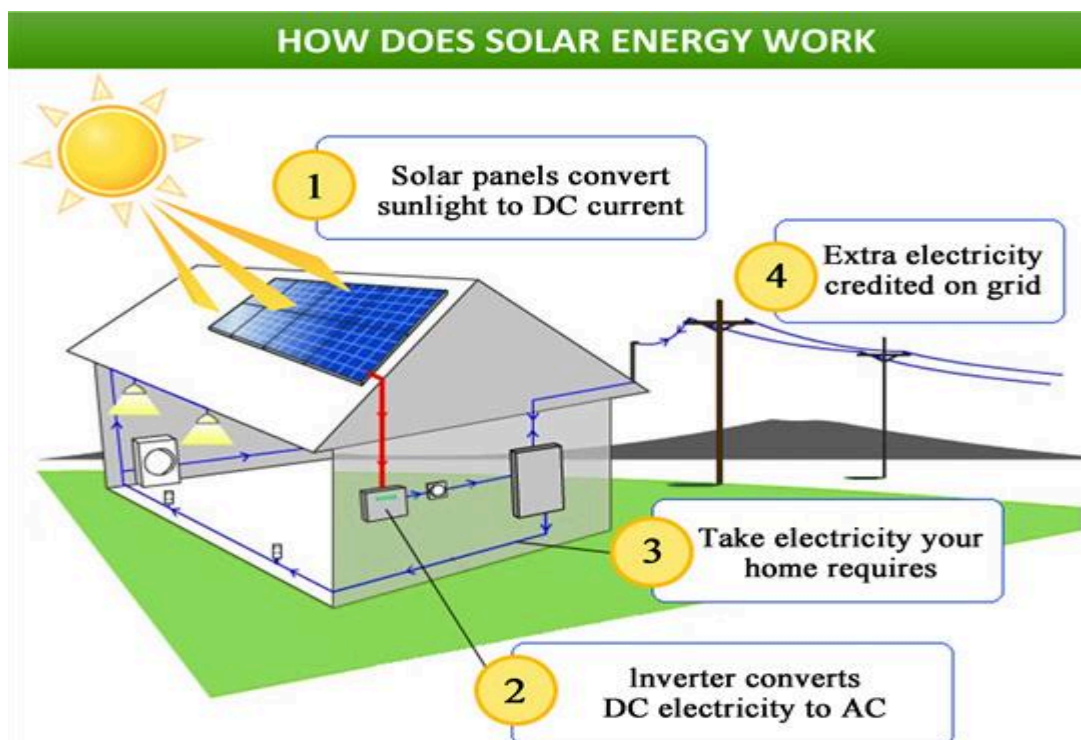


FIGURE 4. How solar energy works (adapted from Sustainableenergyz, 2012).

2.2 Benefits Of Using Solar Energy In Nigeria To Address The Issue Of Electricity Security

Solar energy is limitless and nonpolluting, making it a viable prospective source for green electricity generation. According to Mohammed et al. (2017, 820-838), several wealthy countries have reported improved electrical stability as a result of solar investment. Investing in solar energy harvesting technologies has the potential to reduce or eradicate energy poverty in developing nations while also helping to reduce greenhouse gas emissions. Without a doubt, using solar energy to generate electricity has numerous advantages, including low operational and maintenance costs, a long lifespan of 20 to 30 years between failures, noiseless operation and the absence of moving parts, the availability of PV panels in a variety of sizes or modules across a wide range of power ratings, and a perceived environmental friendliness in terms of greenhouse gas emissions, global warming, ozone layer depletion, and so on. The following are the benefits of using solar energy.

2.2.1 Independent and Reliable Home Energy

Homeowners who install solar energy systems have control over their electricity supply and the ability to use it without relying on traditional sources, which can fail at times. During the day, the solar panels generate electricity that is sent straight to the home's appliances. The solar system's batteries store energy utilized at night to generate electricity for the house, allowing it to become energy-independent (Caliskan, 2017, 488-492.) As a result, life improves, and homes are more environmentally friendly to live in. Solar energy is also energy-reliable since the energy produced by solar panels is stored in batteries, allowing it to power the house at any time or when the sun is not as bright.

2.2.2 Cost-Effective Energy Source

Most Nigerians are familiar with solar energy, but few are aware of the significant cost savings associated with putting solar panels in their houses (Onat & Bayar, 2010, 31083115.) As a result, Nigerians are less reliant on fossil fuels and spend less money on energy. Solarpowered homes will help to mitigate rising energy bills for a variety of reasons. The primary advantage is that it reduces reliance on the public power grid while providing a sustainable energy source. Installing solar panels is similar to constructing a tiny power plant for a home. As a result, homes become less reliant on the public grid, making them more sustainable and affordable to live in.

2.2.3 Greenhouse Development

Solar systems generate power utilizing the sun's energy rather than the world's conventional resources. Natural processes quickly replace this pure, pollutant-free, and practically limitless renewable energy. Solar panel installation in residential complexes is one of the most effective ways to minimize carbon footprints (Pirasteh, Saidur, Rahman, & Rahim, 2014, 133–148.) Solar panels provide a green, clean energy source that has no negative impact on the environment or climate. Solar panels catch sunlight and transform it into energy.

Furthermore, the energy obtained from sunshine is an infinite resource that will never run out. Solar energy is a dependable and safe source that does not emit harmful particles into the atmosphere. The end result is less air pollution and more livable homes and cities. Solar panels are typically installed on roofs or other areas where the sun shines throughout the day. As a result, they may generate power continuously for up to 30 years without generating air pollution.

2.2.4 Low Maintenance Costs

Cleaning solar energy systems once or twice a year should suffice because they frequently need to be kept clean and require little maintenance. For a more satisfactory conclusion, expert cleaning businesses that provide this service may be employed. Many respectable solar panel manufacturers offer guarantees of 20-25 years (Jesuleye & Siyanbola, 2008, 136-141.) Furthermore, there is no wear and tear because there are no moving components. Because it constantly converts solar energy into power and heat, the inverter is typically the only component that must be replaced every five to ten years. To ensure that the solar power system runs efficiently at all times, the wires and inverter must be kept in good condition. After paying for the initial cost of building the solar energy system, there is little cost for maintenance and repairs.

2.2.5 Recyclable Solar Panels

Most solar energy systems include rechargeable batteries, which can store excess energy and be used whenever electricity is needed. These high-quality batteries, which are continually ready to be discharged and refilled, help buildings control their day and night illumination. Silicon and silver, which are two of the numerous components necessary to manufacture solar panels, can be recycled for up to 30 years after they are no longer usable. Solar panel recycling companies collect used solar-powered cells made of semiconductors and other materials. They are recycled into brand-new solar-powered cells that will be employed in new applications such as electrical devices and building security. As a result, recycling can be beneficial for solar panels.

2.3 Obstacles to Adopting Solar Energy in Nigeria

Nigeria and the majority of developing African countries have a serious disadvantage because they are hesitant to develop and maintain their own technologies. Often Nigeria opt for the easy fix of purchasing finished items and services rather than the seemingly difficult route of developing the necessary technology to use the abundant locally available raw materials to manufacture these things and services. As a result, Nigeria kept slipping behind other third-world nations, and things will only worsen if the nation does not start acting differently. The primary barrier to Nigeria's progress in renewable energy and energy efficiency is a lack of legislation and rules (Federal Ministry of Environment, 2013.) The primary barriers to the sector's development are the lack of legislation and policy around renewable energy technology and the requirement to address excessive energy use.

Lack of awareness of the benefits of this technology is yet another major obstacle to the solar energy movement. Few players in the public and business sectors are aware of the potential advantages of solar energy and related technologies. The market is warped as a result of this ignorance and lack of information, which increases the perceived risk of possible renewable energy projects. Kok, Lo, Peters & Ruiters (2011, 5280–5286) state that the reason energy conservation programs have proven so unsuccessful is that they have not always taken into account the entire range of important elements that influence human behavior. Informing the public about the availability, benefits, and prospects of solar energy resources is essential to raising public awareness and igniting interest in the field.

3 RESEARCH METHODOLOGY

Research methodology refers to the precise procedures or techniques used to locate, select, handle, and evaluate data on a topic. A research paper's methodology section allows the reader to evaluate the general validity and dependability of the study. This section provides an explanation of the data collection process. The process of gathering and methodically examining data on crucial factors in order to address certain research questions, test hypotheses, and assess findings is known as data collection. The process of gathering data for research is common to all academic fields, including business, humanities, and social and physical sciences (Roopa, Satya, and Rani, 2012, 37–41.) This research is a conceptual article based on literature. A comprehensive road map showing how solar energy can be used to generate sustainable energy in Nigeria was developed after reviewing the literature on solar energy's potential and the constraints connected with its efficient deployment. The idea also has many benefits that should encourage policymakers to accept and implement it.

A secondary data-gathering technique was implemented. Secondary data refers to information received from a source that has previously been made available in any way. Any study that uses secondary data from literature reviews. Although someone else received the information for a different reason, the investigator used it for another. Secondary data sources for social science include censuses, organizational records, and qualitative or research data. Secondary data is essential because completing a new poll that captures historical progress and developments is impossible. Secondary data collection methods include books, records, biographies, newspapers, published census results or other statistical data, data archives, online articles, journal articles written by other scholars, and databases. (Roopa, Satya, and Rani, 2012, 37–41.)

4 SUSTAINABLE ELECTRICAL ENERGY GENERATION IN NIGERIA THROUGH SOLAR ENERGY ADOPTION

Globally, photovoltaic solar power systems are quickly emerging as the most dependable and promising clean energy technology. According to Statista (2023), global cumulative solar photovoltaic capacity has gradually increased since 2000. Figure 5 shows that in 2022, approximately 239 gigawatts of new PV capacity were constructed, bringing the total cumulative solar PV capacity deployed worldwide to 1,177 gigawatts. However, a key disadvantage shared by most developing African countries, including Nigeria, is a lack of willingness and commitment to investing in the advancement and maintenance of their technologies. Rather than embarking on the seemingly difficult task of developing the technology required to exploit their abundant local raw materials to make these goods and services, they frequently choose the fast fix of purchasing finished goods and services. This has kept most developing countries behind other third-world countries.

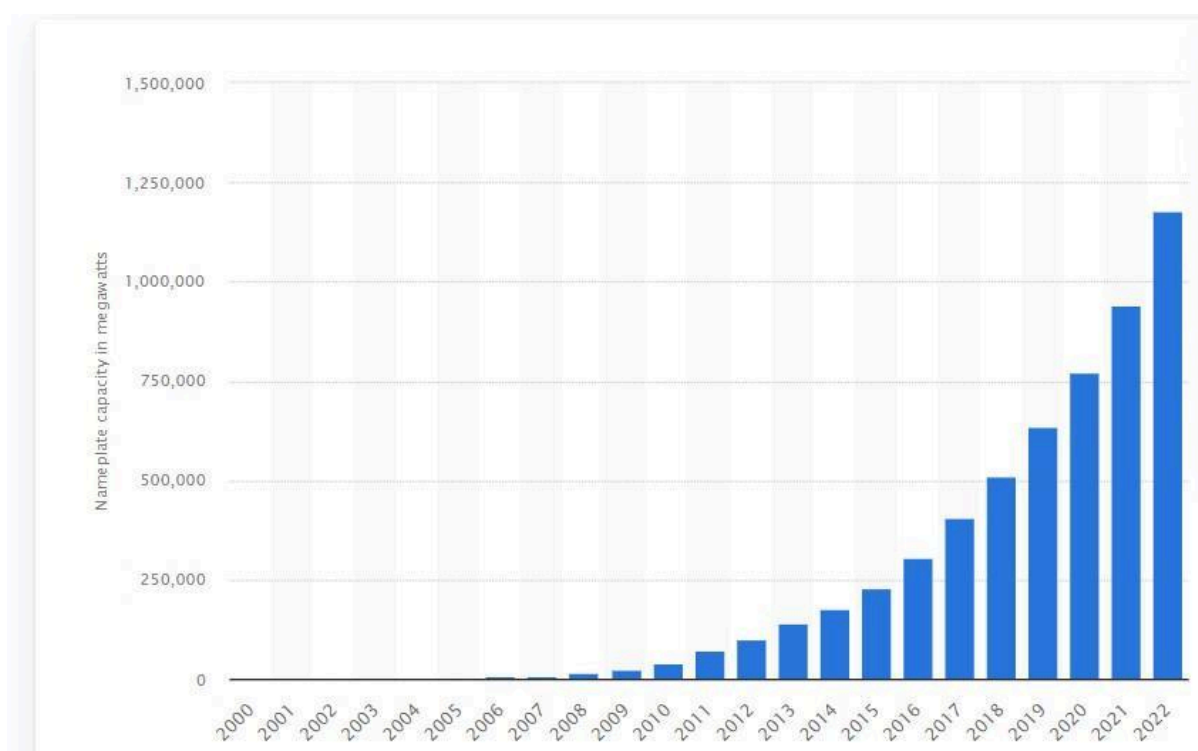


FIGURE 5. Global total installed photovoltaic capacity from 2000 to 2022 (adapted from Statista, 2023).

Although solar photovoltaic (PV) applications have been in Nigeria since the 1970s, they became more well-known in 1980 after the establishment of the Solar Energy Society of Nigeria (SESN) (Solar Energy Society of Nigeria, 2020). An association of importers, marketers, and manufacturers of solar energy products is called SESN. The use of solar PV gained speed in Nigeria after the government's 2004 move to create the Council for Renewable Energy Nigeria (CREN). Reduced reliance on fossil fuels and increased use of renewable energy sources are the objectives of CREN, a body within the Federal Government of Nigeria. Even with Nigeria's abundance of solar resources, adoption of solar PV technology seems to have lagged behind predictions despite this early impetus, forty years after SESN was founded and nearly two decades after CREN was established. Recently, in an effort to accelerate the growth of solar PV in Nigeria, the government, private solar PV producers, and customers came together.

4.1 Adoption Of Solar Photovoltaic In Nigeria

The sun provides Nigeria with around 4909.212 kWh of energy, equivalent to 1.082 million tons of oil (Muye, 2016, 23-28). Figure 2, which shows worldwide solar irradiation, demonstrates that solar radiation is evenly dispersed across the country. This diagram depicts the distribution of solar electricity throughout Nigeria, demonstrating that all areas are appropriate for national solar photovoltaic applications. Nigeria has a greater spectrum of solar irradiation. Nigeria's solar energy potential ranges from 3.5 to 7.5 kWh/m²/day, with the northeast having the highest radiation levels. Despite Nigeria's abundant solar energy resources, only a few states—Bukhari, Delta, Enugu, Lagos, Oyo, and Sokoto—have adopted solar PV to reduce electricity costs. (Osunmuyiwa & Kalfagianni, 2017, 26-40.) According to Emodi and Boo (2015, 356-381), solar PV installations exist in certain northern states of the country, including Kano and Katsina. Even though solar photovoltaics were not used for rural electrification in the country's northern parts until 1985, water pumping and telecommunication were added in the years that followed (Oparaku, 2002, 31-40).

Ohunakin, Adaramola, Oyewola, & Fagbenle (2014, 294–301) claim that Nigeria is adopting solar technology slowly, even with these ostensibly forward-thinking developments in solar photovoltaics. Nigeria experiences a year-round abundance of solar radiation. Nevertheless, despite the Federal Government's substantial financial investment to ensure a sufficiently

sustainable electricity supply for the nation, the enormous potential for solar energy has not yet been realized. Nigeria still lacks the necessary solar radiation measurement infrastructure. Only 1% of the country's landmass will need solar PV technologies installed to surpass current electricity generation levels. Less than 1% of power is generated by solar energy (Ajayi, Ohijeagbon, Nwadialo & Olasope, 2014, 28–36.) There are not many research and development projects in Nigeria that deal with photovoltaic technology. Data collected in 1999 by the Energy Commission of Nigeria (ECN) indicates that approximately forty-four (44) companies and research institutions in Nigeria import and install photovoltaic (PV) systems. Except for Exide Nigeria Limited, no company makes batteries for photovoltaic solar applications (Abdullahi, Garba & Tambuwal, 2020.)

4.2 Factors Affecting Solar Photovoltaic Installation in Nigeria

The nation faces obstacles in increasing solar energy penetration, and sustainable development would suffer without solid penetration. Despite all of its benefits, solar energy is still not used very often due to the challenges that solar photovoltaic systems face. In Nigeria, almost 40% of people do not have access to a reliable electricity supply despite its enormous solar potential, which, if fully utilized, could solve its electricity crisis (Olanite & Nwohu, 2021.) Solar photovoltaic (PV) technology offers a sustainable and renewable energy source, which could greatly aid Nigeria's energy issues. However, several factors affect Nigeria's ability to successfully implement solar PV installations. Here, we examine the key factors influencing solar PV installation in the country, considering economic, regulatory, and environmental factors.

4.2.1 Economic Factors

One of the most significant economic elements impacting solar PV installation in Nigeria is the initial investment cost. Purchase and installation costs for solar panels and associated equipment can be prohibitively expensive for individuals and businesses. On the other hand, subsidies, tax credits, and financing options can help mitigate these challenges. (IEA, 2021.) Government policies that encourage financial support for solar projects are critical to the growth of Nigeria's solar PV industry. The price of electricity from conventional sources is

also quite important. If grid electricity is cheaper than solar, potential investors may hesitate to invest in solar PV systems. The government must develop policies encouraging cost-effective solar energy, making it an appealing option for residential and industrial consumers (Oyedepo, Adaramola, Okeniyi & Fagbenle, 2020.)

4.2.2 Environmental Factors

Solar photovoltaic systems are intrinsically reliant on external factors, specifically the presence of sunlight. Nigeria can efficiently utilize solar energy because it receives an abundance of sunlight. Nonetheless, specific elements like air pollution, weather patterns, and shading can impact how well solar panels work locally. According to Okeniyi, Oyedepo, Adaramola, & Adefarati (2020), conducting site-specific assessments is imperative to maximize the placement of solar installations and guarantee their sustained efficiency. Furthermore, environmental sustainability is becoming a primary global concern. Installing solar photovoltaic systems is consistent with Nigeria's objective to lower carbon emissions and advance clean energy. Solar energy Adoption and acceptance can rise due to government programs and public awareness campaigns highlighting its environmental advantages (Adaramola, Oyewola, & Okeniyi, 2019, 152-166.)

4.2.3 Regulatory Factors

The regulatory framework in Nigeria greatly influences how solar PV installations are adopted. Establishing enabling policies requires clear and encouraging guidelines. Investment in solar PV projects can be stimulated by government incentives like feed-in tariffs, net metering, and streamlined permitting procedures (NEPZA, 2022.) However, a lack of definite and consistent policies could make investors nervous and prevent the growth of the solar business (Adaramola et al., 2019). Grid connection policies and grid reliability are other important concerns. The unpredictability of the electricity supply and the challenges associated with connecting solar systems to the grid may deter potential investors. Improving grid infrastructure and speeding up the connecting process are necessary to increase the viability of solar PV projects (Oyedepo et al., 2020.)

5 FINDINGS AND RECOMMENDATION

The study above shows that Nigeria has a great potential to produce clean energy. However, the country rarely uses solar energy and photovoltaic technology given the fact that it only has less than 1% of its electricity from solar power. This is because of factors like lack of technical expertise, lack of interest on the part of the public, a lack of funding, and inconsistent government policy that hinders the adoption of solar PV technologies. Therefore, many factors, such as economic, regulatory, and environmental considerations, must be addressed before solar PV installations can be successfully implemented in Nigeria. Additionally, the government must implement policies that support investing in solar energy.

To fully solve the challenges facing the utilization of solar photovoltaic technology in Nigeria, community involvement and public-private sector cooperation are essential. The public must know the benefits of adopting this technology. Therefore, the government should ensure to make laws that will encourage private sector participation and increase public knowledge of solar photovoltaic technologies and what they stand to gain. Furthermore, to encourage more awareness of the photovoltaic technology, Nigerian educational institutions should include courses and programs on the installation and maintenance of solar panels and the essential infrastructure into their syllabus. Naturally, this will result in the development of manpower and capacity. The government should also consider putting subsidies on materials required to produce and install solar panels. With these recommendations, the barriers against adopting solar PV technology in Nigeria will be greatly reduced and as a result, there will be an increase in the use of solar energy.

6 CONCLUSION

Nigeria has underutilized its energy resources despite having enormous potential for producing energy. Nigeria has abundant incident solar radiation, which can yield significant benefits with the proper support and resources. The adoption and deployment of solar photovoltaic technologies are highlighted in this research as a means of giving the country a stable power supply. The viability of employing solar photovoltaic technologies in Nigeria to generate electricity from incident solar radiation was demonstrated. Solar energy generation has a brighter future ahead of it, and the good news is that it produces no pollution, no fuel needs, and is free. With its unstable power supply, the country's energy needs cannot be satisfied by conventional energy sources. As a result, photovoltaic solar energy is known as a trustworthy substitute for traditional methods of producing electricity. Utilizing solar energy to meet home energy needs and the needs of rural areas while also providing the industrial sector with grid-supplied electricity can help the country's economy. Therefore, it is essential that the government and other key players in the energy sector create policies and cultivate an environment that will promote the use of photovoltaic technology and solar energy generation. Stakeholders can also benefit significantly from studying and implementing strategies from developed nations excelling in producing solar energy to improve outcomes in this area. Ultimately, many of the issues raised would have been resolved if the suggestions made in this study and others had been followed.

REFERENCES

- Abdullahi, N., Garba, M. & Tambuwal, S. 2020. Overview of Photovoltaic Solar Energy: A Realistic Option for Nigeria's Power Issues. *Journal of Science & Agriculture*, 3(1).
- Adaramola, M., Oyewola, O. & Okeniyi, J. 2019. Renewable energy potentials in Nigeria: Meeting rural energy needs. *Renewable and Sustainable Energy Reviews*, 99, 152-166.
- Adedeji, I., Deveci, G. & Salman, H. 2022. The Incentives of Stabilized Interlocking Clay Bricks for Providing Sustainable Affordable Housing in Nigeria. *Open Access Library Journal*, 9.
- Adedeji, I., Deveci, G., Salman, H. & Abiola, I. 2023. The Benefits of Solar Energy on the Provision of Sustainable Affordable Housing in Nigeria. *Journal of Power and Energy Engineering*, 11, pp. 1-15.
- Ajayi, O., Ohijeagbon, O., Nwadialo, C. & Olasope, O. 2014. New model to estimate daily global solar radiation over Nigeria. *Sustainable Energy Technologies and Assessments*, 5, pp. 28-36.
- Ayodele, T., Olanrewaju, O. & Jimoh, A. 2012. *Energy and climate change: critical reflection on the African continent*. Sustainable Development Africa, 14 (6), pp 84–97.
- Caliskan, H. 2017. Energy, Exergy, Environmental, Enviroeconomic, Exergoenvironmental (EXEN), and Exergoenvironoeconomic (EXENEC) Analyses of Solar Collectors. *Renewable and Sustainable Energy Reviews*, 69, pp. 488-492.
- Davidson O. 2006. Energy for sustainable development: An Introduction. In Winkler, H (Ed.). *Energy Policies for Sustainable Development in South Africa, Option for the Future*. In Sunday Olayinka O. 2013, *Energy in Perspective of Sustainable Development in Nigeria*. *Sustainable Energy*, 1(2), pp. 14-25.
- Emodi, N. & Boo, K. 2015. Sustainable Energy Development in Nigeria: Current Status and Policy Options. *Renewable and Sustainable Energy Review*, 51, 356-381.
- Energy Commission of Nigeria (ECN). 2003. *National Energy Policy*. Available at: https://openjicareport.jica.go.jp/pdf/11846656_03.pdf. Accessed 25 September 2023.
- Energy Commission of Nigeria and United Nations Development Programme (ECN-UNDP). 2005. *Renewable Energy Master Plan (REMP): final draft report*. Available at: <http://www.icednigeria.org/workspace/uploads/nov.-2005.pdf>. Accessed 25 September 2023.
- Federal Ministry of Environment. 2013. *National Policy on Climate Change (NPCC)*. Available at: https://www.all-on.com/media/publications/simplified-guides-to-nigeriasenergy-access-policies-andregulations/_jcr_content/par/textimage.stream/1595008849973/dc8fea0b5aef03ead699

[def51a_c37ec5be56b8e1/national-policy-on-climate-change-npcc.pdf](https://www.seforall.org/sites/default/files/NIGERIA_SE4ALL_ACTION_AGENDA_FINAL.pdf). Accessed 25 September 2023.

Federal Republic of Nigeria, National Council on Power (NACOP). 2016. *National Renewable Energy Action Plans (NREAP) (2015-2030)*. Available at: https://www.seforall.org/sites/default/files/NIGERIA_SE4ALL_ACTION_AGENDA_FINAL.pdf. Accessed 30 September 2023.

Green, M., Emery, K., Hishikawa, Y., Warta, W. & Dunlop, E. 2017. Solar cell efficiency tables (version 50). *Progress in Photovoltaics: Research and Applications*, 25(1), 3-13. Available at: <https://onlinelibrary.wiley.com/doi/10.1002/pip.2909>. Accessed 6 November 2023.

HLPF. 2018. *2018 HLPF Review of SDG implementation: SDG 7- Ensure access to affordable, reliable, sustainable, and modern energy for all*. Available at: https://sustainabledevelopment.un.org/content/documents/195532018_background_notes_SDG_7Final1.pdf. Accessed 3 January 2024.

International Energy Agency (IEA). 2021. *Renewables 2021: Analysis and forecast to 2026*. IEA Publications.

Jacobson, M. & Kammen, D. 2007. A path to sustainable energy by 2030. *Science*, 315(5813), 798-801. Available at: https://www.researchgate.net/publication/38052436_A_Path_to_Sustainable_Energy_by_2030. Accessed 6 November 2023.

Jesuleye, A. & Siyanbola, W. 2008. Solar Electricity Demand Analysis for Improved Access to Electricity in Nigeria. *Nigeria Journal of Solar Energy*, 19, pp. 136-141.

Kok G., Lo S., Peters G. & Ruiter R. 2011. Changing energy-related behavior: An Intervention Mapping approach. *Energy Policy*, 39, pp. 5280 –5286

Lucia, F. 2023. *Global cumulative installed solar PV capacity 2000-2022*. *Energy and environment*. Available at: <https://www.statista.com/statistics/280220/global-cumulativeinstalled-solar-pv-capacity/#:~:text=Global%20cumulative%20installed%20solar%20PV%20capacity%202000%2D2022&text=Global%20cumulative%20solar%20photovoltaic%20capacity,installed%20in%20that%20same%20year>. Accessed 5 December 2023).

Mohammed, Y., Mustafa, M., Bashir, N. & Ibrahim, I. 2017. Existing and recommended renewable and sustainable energy development in Nigeria based on autonomous energy and micro-grid technologies. *Renewable and Sustainable Energy Reviews*, 75(2017), pp. 820–838.

Muye, H. 2016. Adoption of Solar Energy Systems in Remote and Rural Communities of Nigeria. *The International Journal of Science & Technology*, 4, pp. 23-28.

National Export Processing Zones Authority (NEPZA). 2022. *Renewable Energy and Power Generation in Free Trade Zones Guidelines*. Abuja, Nigeria: National Export Processing Zones Authority (NEPZA).

Newsom, C. 2012. *Renewable Energy Potential in Nigeria: Low-Carbon Approaches to Tackling Nigeria's Energy Poverty*. The International Institute for Environment and Development. Available at: <https://www.ied.org/sites/default/files/pdfs/migrate/G03512.pdf>. Accessed 1 October 2023.

Nigeria Embassy. 2013. *About Nigeria. Embassy of the Federal Republic of Nigeria. Washington D.C.* Available at: <https://nigeriaembassyusa.org/>. Accessed 27 September 2023.

Ohunakin, O., Adaramola, M., Oyewola, O. & Fagbenle, R. 2014. Solar Energy Applications and Development in Nigeria: Drivers and Barriers. *Renewable and Sustainable Energy Reviews*, 32, 294-301. Available at: <https://doi.org/10.1016/j.rser.2014.01.014>. Accessed 5 December 2023.

Okeniyi, J., Oyedepo, S., Adaramola, M. & Adefarati, T. 2020. Photovoltaic-wind hybrid renewable energy system design for selected locations in North-East geopolitical zone, Nigeria. *Journal of Cleaner Production*, 261, 121215.

Okoye, C. Taylan, O. & Baker D. 2016. Solar energy potentials in strategically located cities in Nigeria: Review, resource assessment, and PV system design. *Renewable and Sustainable Energy Reviews*, 55, pp 550–566. Available at: <https://www.sciencedirect.com/science/article/abs/pii/S1364032115012332?via%3Dihub>. Accessed 2 October 2023.

Olanite O. & Nwohu, M. 2021. *Overview of Technical Benefits of Microgrid Integration into Nigerian Power System Network in 2020 IEEE / ICECET Cape Town-South Africa*, pp 1-6.

Onat, N. & Bayar, H. 2010. The Sustainability Indicators of Power Production Systems. *Renewable and Sustainable Energy Reviews*, 14, pp. 3108-3115. Available at: https://www.academia.edu/10833702/The_sustainability_indicators_of_power_production_systems. Accessed 2 October 2023.

Oparaku, O. 2002. Photovoltaic Systems for Distributed Power Supply in Nigeria. *Renewable Energy*, 25, 31-40. Available at: [https://doi.org/10.1016/S0960-1481\(00\)00203-2](https://doi.org/10.1016/S0960-1481(00)00203-2). Accessed 5 December 2023.

Osunmuyiwa, O. & Kalfagianni, A. 2017. Transitions in Unlikely Places: Exploring the Conditions for Renewable Energy Adoption in Nigeria. *Environmental Innovation and Societal Transitions*, 22, 26-40. Available at: <https://doi.org/10.1016/j.eist.2016.07.002>. Accessed 5 December 2023.

Owebor K., Diemuodeke, E., Briggs, T. & Imran, M. 2021. Power Situation and renewable energy potentials in Nigeria – A case for integrated multi-generation technology. *Renewable Energy*, 177, pp. 773-796.

Oyedepo, S., Adaramola, M., Okeniyi, J. & Fagbenle, R. 2020. Sustainable energy development in Nigeria: Current state and policy implications. *Renewable and Sustainable Energy Reviews*, 117, 109488.

Pirasteh, G., Saidur, R., Rahman, S. & Rahim, N. 2014. A Review on Development of Solar Drying Applications. *Renewable and Sustainable Energy Reviews*, 31, pp. 133-148.

Ramchandra P. & Boucar D. 2011. *Green Energy and Technology*. Springer, London Dordrecht Heidelberg New York.

Roopa, S & Menta Satya, R. 2012. Questionnaire Designing for a Survey. *The Journal of Indian Orthodontic Society*, 46, pp. 37-41.

Rural Electrification Agency. 2019. *Bayero University Kano Hosts Africa's largest Solar Hybrid Power Plant—The Gaurdian*. Available at: <https://rea.gov.ng/bayero-university-kanohosts-africas-largest-solar-hybrid-power-plant-gaurdian/>. Accessed 29 September 2023.

Solar Energy Society of Nigeria (SESNG). 2020. *Solar Energy Society of Nigeria*. Available at: <https://sesnng.pagaloo.com/d/org>. Accessed 5 December 2023.

Sustainableenergyz. 2012. *How Solar Energy Works? Renewable Energy Source*. Available at: <https://sustainableenergyz.wordpress.com/2012/04/17/how-solar-energy-works/>. Accessed 29 September 2023.

Tsighe, Z. 2001. Opportunities and Constraints for Sustainable Energy in Eritrea. In *Habtetsion, S., Tsighe, Z. & Anebrhan, A. (Eds.) Sustainable Energy in Eritrea, Proceedings of a National Policy Seminar Held on October 30-31, Asmara, Eritrea. In Sunday Olayinka O. 2013, "Energy in Perspective of Sustainable Development in Nigeria*. *Sustainable Energy* 1(2), pp. 14.25.

Usman, Z., Abbasoglu, S., Ersoy, N. & Fahrioglu, M. 2015. Transforming the Nigerian power sector for sustainable development. *Energy Policy*, 87(2015), pp 429–437. Available at: https://www.researchgate.net/publication/282589730_Transforming_the_Nigerian_power_sector_for_sustainable_development. Accessed 1 October 2023.

Villegas, P. 2018. Benefits of Solar Energy for Belize. *The Belize Times*, Issue No. 5093. Available at: https://www.researchgate.net/publication/326019756_BENEFITS_OF_SOLAR_ENERGY_FOR_BELIZE. Accessed 1 October 2023.

