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From Fossil Fuels to Solar Power: Nigeria's Renewable Energy Transition in the African Context

Paschal Okiroro Iniaghe

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Abstract: *Nigeria, Africa's most populous nation and a leading oil producer, faces a paradox: abundant fossil fuel reserves coexist with persistent electricity shortages. As the country navigates its transition to renewable energy, solar power emerges as a central solution. Nigeria possesses some of the highest solar irradiation potentials in the world (about 5.5 kWh/m^2/day), which, if adequately harnessed, could significantly expand energy access, particularly in off-grid and rural communities where traditional power infrastructure is lacking. Beyond bridging the energy gaps, solar deployment offers co-benefits such as reducing carbon emissions, creating employment opportunities, and promoting economic growth. However, the transition is not without challenges. The high initial cost of solar installations, limited access to financing, and inadequate technical expertise constrain widespread adoption. Despite these constraints, solar energy remains a transformative pathway for Nigeria, and Africa at large, to advance sustainable development while contributing to global climate goals. By capitalizing on its abundant solar resources and addressing existing structural limitations, Nigeria can be among the leading nations in Africa's renewable energy transition and foster a cleaner and more resilient energy future.*

Keywords: *Energy access, energy transition, carbon emissions, sustainable development*

Paschal Okiroro Iniaghe
Department of Chemistry, Federal University Otuoke, Bayelsa State, Nigeria
Email: iniaghepo@fuotuoke.edu.ng
Orcid id: 0000-0003-0534-6660

1.0 Introduction

Nigeria, adjudged to be Africa's largest economy, is endowed with an abundance of natural renewable and non-renewable resources (Olayungbo, 2019). As a consequence, the economy and energy sector of Nigeria are deeply tied to fossil fuels, particularly crude oil and natural gas. According to the International Monetary Fund (IMF, 2013), oil and gas account for about 96.9% of Nigeria's export revenues. The country's oil reserve was put at 37.2 billion barrels (BP, 2016), while its natural gas estimates were put at 187 trillion standard cubic feet (scf), including 76.4 trillion scf of non-associated gas (Heinrich-Böll-Stiftung, 2014; Rapu, et al., 2015).

The role of energy in the economic growth, progress, and development of any nation cannot be overemphasized. However, dependence on fossil fuels for energy generation presents both economic and environmental risks—gas flaring, oil spills, and greenhouse gas emissions—remain persistent challenges. Additionally, despite being a leading oil exporter, Nigeria's domestic electricity supply is highly unreliable, in spite of the billions of dollars reportedly disbursed by successive governments over the last two decades (Chanchangi *et al*., 2022). The official installed capacity of 12,500 MW (dominated by natural gas (88%) and the rest from hydro) reportedly delivered 4087 MW in the year 2020, accounting for about 33% (World Bank, 2020), leaving about one hundred million citizens off-grid or facing frequent outages (Akinyele *et al*., 2017).

According to Tracking SDG7, 85 million Nigerians (accounting for 43% of the population) do not have access to electricity, with only about 65.9% of the population having access, and where it does exist, it is often unreliable (IEA, 2018). Electricity is a catalyst in health, education and other forms of social development (World bank, 2020). But the huge shortfall in electricity generation in residential and commercial sectors led to a switch to off-grid power generation (Ogundari *et al*., 2017). These off-grid electricity generations are primarily produced using diesel and gasoline generators, and an average of 84% urban household depend on gasoline or diesel-powered generators for generating electricity (IEA Report, 2015). Against this backdrop, there was an increase in the search for alternative and sustainable power generation, and this led to the adoption of solar energy.

Given Nigeria's high solar irradiation, solar energy offers a viable alternative pathway towards sustainable development. As a result, solar imports surged—over 4 million solar panel units were imported in 2023 alone, valued at over 200 million USD—as households seek reliable alternatives to expensive diesel generators (PwC Nigeria, 2025). Furthermore, the African continent, generally endowed with vast solar potential, has the opportunity to lead the shift from fossil fuels to renewable energy sources. Solar energy is thus, emerging as a viable solution in sub-Saharan Africa where grid expansion is expensive. It thus offers a promising pathway for achieving sustainable development, addressing energy poverty, and reducing greenhouse gas emissions.

Nigeria receives an average solar radiation of 5.5 kWh/m²/day, making it one of the most solar-abundant countries in Africa (Osinowo *et al*., 2015). Northern Nigeria in particular is blessed with abundant solar resources, receiving an average of 6.5 h of sunlight per day (Oweibor *et al*., 2021). Figure 1 is Nigeria's map showing the nation's solar potential. Experts estimates that harnessing only 1% of Nigeria's landmass for solar panels could generate enough electricity (up to 210 GW) to meet the nation's energy needs (CLG, 2024; IRENA and AfDB, 2022). Nigeria's premier solar energy application occurred in 1985 via street lightning in Kwakwalawa Village in Sokoto State (Ilenikhena and Ezemonye, 2010). Several initiatives, such as the Nigeria Electrification Project (NEP) and private sector-led mini-grid developments, are already harnessing this potential. Rural communities, particularly those off the national grid, stand to benefit greatly from decentralized solar systems that provide reliable and clean electricity.

Despite the abundance of literature on Nigeria's energy challenges and the documented potential of solar power, existing studies have largely examined these issues in isolation—focusing either on technical feasibility, energy access patterns, or regional case studies (Ugulu, 2019; Abdullahi et al., 2022; Erebor and Adedire, 2023; Ajia, 2025; Dinneya-Onuoha, 2025; Lawal et al., 2025). Few studies provide an integrated assessment that situates Nigeria's renewable energy transition within the broader African context while simultaneously evaluating the economic, environmental, and policy dimensions that shape solar adoption (IEA, 2018; IRENA & AfDB, 2022). Moreover, there is limited scholarly analysis that connects Nigeria's solar potential with practical implementation challenges such as financing constraints, infrastructural deficits, technological readiness, and market dynamics. This gap highlights the need for a comprehensive synthesis that explains Nigeria's transition trajectory, compares it with continental developments, and identifies the structural barriers that continue to hinder large-scale solar deployment.

The aim of this study is to examine Nigeria's transition from fossil fuels to solar energy within the African context by analyzing its renewable energy potential, current adoption patterns, existing infrastructural and policy limitations, and the opportunities for expanding solar deployment. Specifically, the study seeks to evaluate Nigeria's solar resource base, assess the drivers and constraints of solar uptake, and highlight how the country's transition aligns with continental trends in Africa's energy evolution.

This study is significant because it provides a timely and comprehensive understanding of Nigeria's renewable energy transition at a period marked by rising energy demands, declining fossil fuel viability, and increasing global commitments to decarbonization. By identifying key opportunities and constraints affecting solar energy adoption, the study offers evidence-based insights that can guide policymakers, development agencies, and private-sector stakeholders in designing effective strategies for expanding renewable energy access. Additionally, situating Nigeria's progress within the African context enhances the broader discourse on sustainable development, energy security, and climate resilience across the continent. The findings contribute to ongoing regional and global efforts to promote clean energy transitions and support initiatives aimed at reducing carbon emissions while improving energy access for underserved populations.

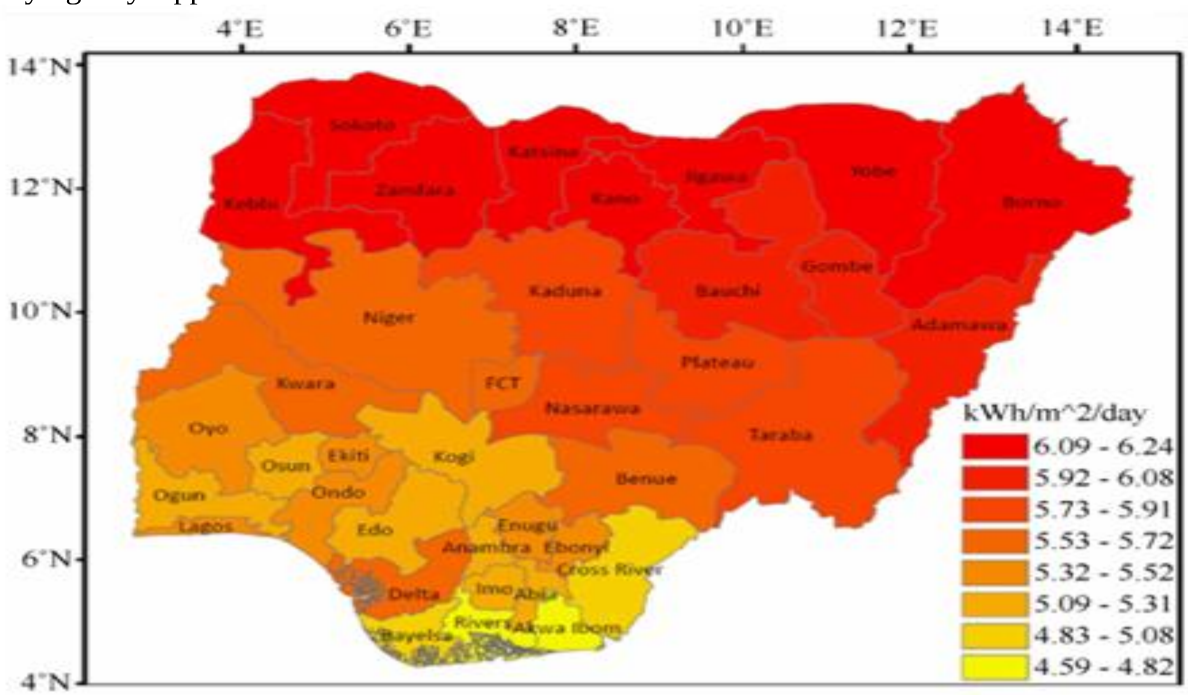

Fig. 1: Map of Nigeria showing the Solar Potential of Nigeria (Muye, 2016)

1.1 Solar power potential in Africa

The opportunities of solar energy in Africa's energy transition include, but are not limited to**:**

i. **Abundant Solar Resources:** Africa is blessed with some of the highest solar irradiation levels in the world. According to Kuhn (2025), Egypt dominates the global sunshine rankings with an astonishing 3,500–4,000 hours of sunshine annually. This is followed by Sudan, Libya, Chad, Niger, and Mali, each receiving over 300 days of sunshine annually. Nigeria, though not placed among the top 15 countries that receive over 300 days of sunshine, is reported to have an annual average sunshine duration of about 6.25 hours, ranging from 3.5 hours in the coastal regions to 9.0 hours in the north (Iweyemi, 2008; Ohunakin, 2010). This abundant solar potential positions the continent as a prime candidate for solar energy deployment. Several African countries have already made significant investments in large-scale solar projects, demonstrating the feasibility and benefits of harnessing solar power. For instance, Morocco's Noor Ouarzazate Solar Complex is one of the world's largest concentrated solar power plants, capable of generating up to 580 MW of electricity (PPIAF, 2024). By tapping into its vast solar resources, Africa can diversify its energy mix and reduce its reliance on fossil fuels.

ii. **Improving Energy Access:** Solar energy presents an effective solution to the problem of lack of energy access, particularly in rural and remote areas where traditional grid infrastructure is costly and impractical to implement. Solar power is safe, efficient, non-polluting, and reliable, and has a very exciting prospect of fulfilling the world’s future energy needs (Chowdhury et al., 2020). Decentralized solar systems, such as solar home systems, can provide affordable and reliable electricity to off-grid communities, improving their quality of life and enabling economic activities that rely on electricity. For example, in Nigeria, solar home systems have transformed energy access, allowing households to power lights, charge phones, and run small appliances.

***iii. Economic Growth and Job Creation**:* The solar energy sector holds significant potential for economic growth and job creation in Africa. As solar projects expand, they generate employment opportunities across various stages, from manufacturing and installation to maintenance and operation. According to the International Renewable Energy Agency (IRENA & AfDB, 2022), the renewable energy sector could create millions of jobs in Africa by 2050.

iv. ***Reducing Carbon Emissions*****:** Solar energy is a clean and renewable power source that does not emit greenhouse gases during operation, making it a vital tool for reducing carbon emissions and, by extension, combating climate change. By transitioning to solar energy, African countries can significantly decrease their carbon footprint and contribute to global efforts to limit temperature rise (IEA, 2015).

v. Enhancing Energy Security: Increasing solar energy adoption can enhance Africa's energy security by reducing dependence on imported fossil fuels. Solar energy provides a reliable and sustainable power source that can stabilize electricity supply, especially in regions prone to energy shortages.

vi. ***Technology Transfer and Innovation*****:** Africa's solar energy transition presents opportunities for technology transfer and innovation. Collaborations with international partners can facilitate the transfer of cutting-edge technologies and best practices, enabling African countries to leapfrog to advanced energy solutions (Olawuyi, 2018; Gebreslassie et al., 2022). Moreover, local entrepreneurs and startups are driving solar energy innovation by developing tailored solutions that address the continent's unique challenges. Recent evidence from Kenya and Nigeria shows that households and businesses connected to decentralized solar mini-grids experienced dramatic improvements in income, productivity, and health within a year of access (Carabajal et al., 2021). These findings underscore that solar technologies, when adapted to local contexts through innovative business models, not only close the energy access gap but also catalyze broader social and economic transformation. For example, companies like M-KOPA in Kenya are pioneering pay-as-you-go solar systems, making solar energy more accessible and affordable for low-income households (M-KOPA, 2024).

2.0 Nigeria's Solar Transition Programmes & Investments

2.1 Solar Power Naija

The Solar Power Naija Programme (SPN) was launched by the Federal Government of Nigeria as part of the Economic Sustainability Plan. The programme aims to achieve the roll-out of 5 million new solar-based connections in unserved and underserved communities and businesses not connected to the grid—via Solar Home Systems (SHS) and mini-grids. This initiative is expected to provide electricity access to roughly 25 million individuals (REA, 2025). The programme also aims to boost local manufacturing, create 250,000 jobs, and yield significant fiscal and import savings.

Under the Nigeria Electrification Project (NEP), REA has deployed over 103 solar hybrid mini-grids, reaching around 46,661 verified connections and impacting over 230,000 people. By mid-2023, the NEP had achieved the deployment of 67 additional solar mini-grids, exceeding 52 MW of installed capacity and supporting more than one million SHS installations (REA-NEP, 2023; Athekame, 2023).

2.2 Major Investment Moves

In March 2025, Nigeria signed a $200 million deal with WeLight, a pan-African Distributed Renewable Energy (DRE) company. Backed by the World Bank and AfDB, the partnership aims to support the development of 400 mini-grids and 50 metro-grids. These projects are expected to electrify up to 2 million residents (TRT Global, 2025). This MoU represents a major step toward expanding clean electricity access in Nigeria and aligns with WeLight's broader ambition of becoming a leading pan-African DRE provider.

Earlier, in March 2024, a 20 MW pilot solar plant was announced—part of a planned 300 MW hydro-solar hybrid facility at the Shiroro hydropower concession (Ajayi, 2024; NSIA, 2024).

The Energy Commission of Nigeria (2019) reported that the Nigerian Government, through the Nigerian Bulk Electricity Trading Plc (NBET), signed Power Purchase Agreements (PPAs) with 14 independent power producers for a total of 1,125 MW of solar power.

More recently, the Nigerian Government has intensified efforts to expand solar deployment in tertiary institutions through the Energizing Education Project (EEP) and complementary renewable energy programmes. To date, 24 federal universities and teaching hospitals are reportedly connected to solar mini-grids, with additional institutions scheduled for integration under the project's fourth phase (Nigerian Observer, 2025).

In support of these initiatives, the Federal Government allocated ₦100 billion in the 2025 national budget for the installation of solar mini-grids in selected universities and hospitals under the National Public Sector Solarization Initiative (Vanguard, 2025). These investments not only reduce reliance on fossil fuels but also foster innovation in solar technologies, enabling universities to serve as hubs for clean energy research and adoption.

3.0 Solar Energy's Role in Sustainable Urban Development

There are two types of solar technologies—photovoltaic (PV) and concentrated solar power (CSP) (Boubou et al., 2015), with PV dominating the Nigerian market (Okereke et al., 2020). Solar energy offers a sustainable solution for urban centers, with applications ranging from rooftop solar panels to solar-powered streetlights, and the generated power can be either used directly or stored in batteries for future use (Okereke et al., 2020). Akinola (2023) classified solar PV applications into three—solar lanterns (small solar units less than 10 watt-peak (Wp)), solar home systems (ranging from 10 to 150 Wp), and solar mini-grids (which combine multiple solar panels).

Integrating solar power into urban planning can reduce the environmental impact of cities and support the development of smart, sustainable urban environments. For instance, integrating Internet of Things (IoT)-enabled monitoring systems can improve solar efficiency and management (Nath et al., 2024). Furthermore, solar energy can support urban transportation systems by providing power for electric vehicles and public transport, contributing to cleaner and more efficient mobility solutions. The deployment of solar panels is expected to accelerate further due to decreasing panel costs, targeted government subsidies, manufacturer-supported incentives for initial installations, and improvements in solar conversion efficiency (Sodhi et al., 2022).

Solar energy can play a critical role in addressing the interconnected challenges of the water-energy-food nexus. Solar-powered irrigation systems can support agricultural productivity by providing reliable water supply for farming (Durga et al., 2023), while solar desalination technologies can deliver clean water for drinking and irrigation in water-scarce regions (Madhuri et al., 2025). By enhancing energy access and improving resource-use efficiency in these sectors, solar energy contributes directly to food security and sustainable water management—two of Africa's most pressing development challenges.

The adoption of solar energy aligns with global development goals, including the United Nations Sustainable Development Goals (SDGs). Specifically, solar energy contributes to Goal 7 (Affordable and Clean Energy) by providing sustainable and reliable power to all, and Goal 13 (Climate Action) by reducing carbon emissions and mitigating climate change impacts (IEA et al., 2025). Through sustained investment in solar infrastructure, African countries can advance progress toward these goals and promote long-term sustainable development across the continent.

4.0 Technology and Sustainability of Solar Systems

4.1 Inverter Technology and Efficiency

Inverters convert direct current (DC) from solar panels into alternating current (AC) for household and industrial use. In Nigeria, where unreliable grid supply forces widespread reliance on hybrid systems (solar + grid + generator), smart inverters play a crucial role in load balancing, surge protection, and energy efficiency. Advances in hybrid inverters allow seamless switching between grid, solar, and storage—a capability that is particularly valuable during prolonged blackouts (Hassan et al., 2023). However, inadequate quality control and the continued importation of substandard inverters remain major challenges, often resulting in frequent system failures and eroding consumer confidence.

4.2 Battery Systems and Storage Challenges

Energy storage—mostly lithium-ion and lead-acid batteries—is indispensable for solar adoption in Nigeria, where the evening peak in electricity demand coincides with zero solar output. Lead-acid batteries dominate because they are cheaper, but they degrade faster under Nigeria's hot climate, require regular maintenance, and pose significant environmental hazards if improperly disposed of. Metal-ion batteries, especially lithium-ion, offer longer life cycles (Meng et al., 2022) and higher efficiency, but their long-term sustainability is constrained by the uneven global distribution of lithium reserves and rising market prices (Dunn et al., 2021; Kiai et al., 2024). Additionally, the lack of recycling infrastructure means most batteries end up in open dumpsites, releasing toxic heavy metals into soil and water—posing health risks and undermining the environmental benefits of renewable energy.

4.3 End-of-Life (EoL) Management

Solar panels typically have a lifespan of 25 years (Chowdhury et al., 2020). However, based on economic and technical trends, many panels may be replaced after as few as seven years (Sodhi et al., 2022). This implies that the volume of EoL solar panels will be substantial, with projections reaching 60–77 million tons by 2050 (Bogust & Smith, 2020).

The primary challenge in the disposal of EoL solar panels is that they contain not only valuable materials such as silicon, silver, and aluminium, but also trace amounts of toxic metals such as cadmium and lead (Jung et al., 2016; Abdo et al., 2023; Durga et al., 2023). While the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive (2012/19/EU) and the Extended Producer Responsibility (EPR) framework require manufacturers to handle the collection and recycling of EoL electronic devices, most solar panels in Nigeria currently end up in general waste streams due to limited specialized recycling facilities and weak regulatory enforcement**.** Notably, the WEEE Directive now applies to solar panels in Europe, recognizing them officially as hazardous electronic waste (Mahmoudi et al., 2019; Abdo et al., 2023).

The main components of silicon-based solar panels include an aluminium frame, glass, encapsulant layers (such as ethylene vinyl acetate binding the solar cells), a backsheet, and a junction box (Abdo et al., 2023). The commonest method of recycling EoL solar panels is to separate and recycle the aluminium frame (Farrell et al., 2020). However, most recycling initiatives currently recover only the aluminium component, leaving other valuable or hazardous materials unprocessed (Abdo et al., 2023).

5.0 Constraints and Challenges in Solar Energy Transition

a) High Initial Costs and Financing Barriers

One of the primary challenges facing solar energy adoption is the high initial cost of solar installations, particularly the batteries required for effective storage (Akinola, 2023). Although global solar technology prices have decreased significantly due to increased adoption and technological breakthroughs (Arent et al., 2017; Abdullahi et al., 2017), the upfront investment required remains prohibitive for many households and small businesses.

In Nigeria, this challenge is further intensified by heavy reliance on imported solar panels, inverters, and batteries, making prices vulnerable to exchange-rate fluctuations and high import duties. Limited access to affordable finance—especially for rural communities and small enterprises—combined with the absence of structured credit facilities or targeted subsidies, continues to hinder widespread adoption. Additionally, Nigeria's inadequate local manufacturing capacity keeps system costs high and slows national progress toward solar self-sufficiency.

These obstacles collectively restrict large-scale deployment of solar systems and underscore the need for stronger financial mechanisms, domestic manufacturing incentives, and supportive technology-transfer policies.

b) Technical Expertise and Skills Gap

The successful deployment and long-term operation of solar energy systems require trained technicians, engineers, and maintenance professionals. However, many African countries, including Nigeria, lack sufficient human capacity across the solar value chain—from project design and installation to safety assessments and system maintenance. Sub-Saharan Africa, despite having over 600 million people without electricity, hosts only about 76,000 renewable energy jobs (World Bank, 2018).

This limited workforce often results in substandard installations, poor system optimization, safety concerns, and reduced performance of solar assets. The deficiency in technical capacity also slows innovation and inhibits the development of locally relevant solar solutions.

Capacity-building initiatives, specialized vocational training, and public education campaigns are therefore essential to equip the workforce with the expertise needed to drive Africa's solar transition (Durga et al., 2023).

c) Improper Fundamental Design and Poor Maintenance

Improper system design remains a widespread challenge in many solar installations across Nigeria. Typical design flaws include overestimation of irradiation levels, undersized PV arrays, insufficient battery capacity, underestimation of energy demand, and the use of inappropriate battery technologies (Sambo et al., 2017). These errors often shorten the lifespan and degrade the efficiency of solar systems.

Solar PV installations also require routine maintenance such as regular cleaning of panel surfaces and timely replacement of worn components. Dust accumulation alone can reduce panel output significantly—sometimes by as much as 30%—yet such preventive maintenance is rarely practiced.

Inadequate after-sales services and a lack of standardized maintenance protocols further contribute to premature system failure and user dissatisfaction.

d) Land Use and Environmental Concerns

Large-scale solar farms require substantial land areas, which often results in competition over land rights—especially in densely populated regions or agriculturally productive zones. Converting farmland or natural ecosystems for solar farm development can fundamentally alter land-use patterns and negatively impact the environment (Zhang et al., 2024).

Potential environmental impacts include habitat fragmentation, biodiversity loss, soil degradation, and disruption of local ecological systems. Moreover, modelling studies of ultra-large solar farms in the Sahara Desert demonstrate that high-density solar installations can alter regional atmospheric circulation and affect global climate systems (Durga et al., 2023; Long et al., 2024).

These insights underscore the importance of rigorous environmental impact assessments, sustainable land-acquisition frameworks, and community-inclusive planning before project execution.

e) An Emerging Waste Stream

The global solar industry is approaching a critical point, as first-generation photovoltaic (PV) installations near their end-of-life phase. Projections estimate that global PV waste will reach 1.7 million tonnes by the early 2030s and rise to approximately 77 million tonnes by 2050 (Chowdhury et al., 2020). In Nigeria, this challenge is compounded by extensive use of battery systems.

Lithium-ion batteries, though efficient, face sustainability challenges due to the limited and uneven distribution of lithium resources in the earth's crust (Dunn et al., 2011).

Their disposal also releases toxic substances into the environment if not properly managed (Akinola, 2023).

Lead-acid batteries—still widely used due to their lower cost—pose an even greater environmental threat. In Nigeria, many lead-acid batteries are recycled informally, exposing communities to soil contamination and elevated blood lead levels among children (Adie and Osibanjo, 2009; Olawoyin & Ogunride, 2025). The absence of structured recycling infrastructure, lack of producer-responsibility regulations, and weak environmental enforcement highlight the urgent need for a national solar waste-management framework.

6.0 Conclusion

Nigeria's transition from fossil fuel dependence toward renewable energy—particularly solar power—represents a transformative shift in the nation's energy landscape. While fossil fuels have historically dominated Nigeria's energy system, the country is now at a pivotal moment where solar energy offers a viable pathway for addressing persistent electricity shortages and reducing greenhouse-gas emissions. Government interventions such as Solar Power Naija, the Nigerian Electrification Project (NEP), and a growing portfolio of private-sector and internationally funded investments show encouraging progress.

However, realizing the full potential of solar energy requires confronting a series of structural challenges. These include financing barriers, limited local manufacturing, inadequate energy-storage infrastructure, and the absence of a comprehensive policy framework. Equally critical is the establishment of efficient end-of-life pathways for solar panels and batteries, which contain both valuable materials and hazardous substances.

If effectively managed, solar energy can deliver broad socio-economic benefits—enhancing energy access, supporting job creation, and strengthening national energy security.

Beyond Nigeria, Africa's wider shift toward renewable energy presents both an environmental necessity and an economic opportunity. In Nigeria's context, solar power remains the most viable solution for bridging the energy-access gap while reducing dependency on fossil fuels. However, the sustainability of this transition depends not only on technology adoption but also on responsible management of solar components, including inverters, storage systems, and end-of-life materials.

Large-scale solar expansion must therefore be guided by responsible land-use planning and environmental safeguards to avoid unintended consequences. If Nigeria successfully overcomes these challenges through innovative policies, targeted financing, circular-economy practices, and capacity development, it can become a model for other African nations seeking to transition from fossil fuels to clean, renewable energy.

7.0 References

Abdo, D. M., El-Shazly, A., & Medici, F. (2023). Recovery of valuable materials from end-of-life photovoltaic solar panels. *Materials,* 16, 7, pp. 2849. https://doi.org/10.3390/ma16072840

Abdullahi, D., Suresh, S., Renukappa, S., and Oloke, D. (2017). Barriers for implementing solar energy initiatives in Nigeria: An empirical study. *Smart and Sustainable Built Environment,* 11, 3. https://doi.org/10.1108/SASBE-06-2020-0094

Abdullahi, D., Renukappa, S., Suresh, S., & Oloke, D. (2022). Key Barriers to implementing solar energy in Nigeria: A critical analysis. *IOP Conference Series: Earth and Environmental Science,* 83, Article ID: 012015. https://doi.org/10.1088/1755-1315/83/1/012015

Adie, G. U., & Osibanjo, O. (2009). Assessment of soil-pollution by slag from an automobile battery manufacturing plant in Nigeria. *African Journal of Environmental Science and Technology,* 3, 9, pp. 239-250. https://doi.org/10.5897/AJEST09.086

Ajayi, O. (2024). *Nigeria unveils 20 MW solar power plant project in Shiroro. The Electricity Hub*. Retrieved from https://theelectricityhub.com/nigeria-unveils-20-MW-solar-power-plant-project-in-shiroro

Ajia, A. T. (2025). Policy challenges and opportunities for renewable energy development in Nigeria. A systematic review. *African Journal of Environmental Sciences and Renewable Energy,* 18, 1, pp. 115-137. https://doi.org/10.62154/ajesre.2025.018.010660

Akinola, A. A. (2023). Solar photovoltaics development in Nigeria: Drivers, barriers, and policies. Energy and Power Engineering, 15, 10, 10, pp. 315-328. https://doi.org/10.4236/epe.2023.1510017.

Akinyele, D. O., Rayudu, R. K., & Nair, N. K. C. (2017). Life cycle impact assessment of photovoltaic power generation from crystalline silicon-based solar modules in Nigeria. *Renewable Energy* 101, pp. 537-549

Arent, D., Arndt, C., Miller, M., Tarp, F. and Zinaman, O. (2017) *The Political Economy of Clean Energy Transition*. Oxford University Press, Oxford. https://doi.org/10.1093/oso/9780198802242.001.0001

Athekame, C. (2023). REA deploys 103 mini-grids across the country - MD. News Agency of Nigeria. Retrieved from nannews.ng/2023/08/23/rea-deploys-103-mini-grids-across-the-country-md/

Bogust, P., & Smith, Y. R. (2020). Physical separation and beneficiation of end-of-life photovoltaic panel materials: utilizing temperature swings and particle shape. JOM 72, 2615-2623.

British Petroleum, BP (2016). BP Statistical Review of World Energy 2016 (65th ed.). Retrieved from https://oilproduction.net/files/especial-BP/bp-statistical-review-of-world-energy-2016-full-report.pdf.

Boubou, N.E. (2015). *Assessing the performance of demand-side strategies and renewables: cost and energy implications for residential sector.* Doctoral dissertation, University of Texas at Austin.

Carabajal, A. T., Orsot, A., Moudio, M. P. E., Haggai, T., Okonkwo C. J., Jarrard, G. T. III., & Selby, N. S. (2023). Social and economic impact analysis of solar mini-grids in rural Africa: a cohort study from Kenya and Nigeria. *Environmental Research: Infrastructure and Sustainability* 4, 2, 025005. https://doi.org/10.1088/2634-4505-ad4ffb

Chanchangi, Y. N., Adum F., Ghosh, A., Sundaram, S., & Mallick, T. K. (2022). Nigeria's energy review: Focusing on solar energy potential and penetration. *European Journal of Futures Research*, 25, pp. 5755-5796

Chowdhury, M. S., Rahman, K. S., Chowdhury, T., Nuthammachot, N., Techato, K., Akhtaruzzaman, M., Tiong, S. K., Sopian, K., & Amin, N. (2020). An overview of solar photovoltaic panels' end-of-life material recycling. Energy Strategy Reviews, 27, 100431. Pp.https://doi.org/10.1016/j.esr.2019.100431.1.

CLG (2024). Bridging Nigeria's energy gap: why solar power is the solution. Retrieved from https://clgglobal.com/bridging-nigerias-energy-gap-why-solar-power-is-the-solution/cl.

Dinneya-Onuoha, E. (2025). Unlocking renewable energy materials in Nigeria: abailability, application, amnd roadmap for sustainability. *RSC Sustainability,* 3, pp. 2534-2566. https://doi.org/10.1039/D5SU00121H

Dunn, B., Kamath, H., & Tarascon, J-M. (2011). Electrical energy storage for the grid: A battery of choices. Science, 334, 6058, pp. 928-935. https://doi.org/10.1126/science.1212741

Durga, N., Mishra, S., Magombeyi, M. S., Ofosu, A., Matambo, C., Pavelic P., Hagos, F., Melaku, D., Verma, S., Minh, T., Schmitterm P., & Ringler, C. (2023). *Solar energy for irrigation in sub-Saharan Africa: a review.* Preprint. Researchgate

Energy Commission of Nigeria (2019) Integration of Solar Photovoltaic into the Grid. Abuja.

Erebor, E. M., & Adedire, F. M. (2023). Energy transition policy, efficiency and implementation strategies in the Nigerian built environment. *Journal of Environmental Sciences,* 22, 1. https://doi.org/10/5281.zenodo.10051225

Farrell, C. C., Osman, A. I. Doherty, R., Saad, M., Zhang, X., Murphy, A., *et al*. (2020). Technical challenges and opportunities in realizing a circular economy for waste photovoltaic modules. *Renewable and Sustainable Energy Resource* 128, 109911. https://doi.org/10.1016/j.rser.2020.109911

Gebreslassie, M. G., Cuvilas, C., Zalengra, C., To, L. S., Baptista, I., Robin, E., *et al.* (2022). Delivering an off-grid transition to sustainable energy in Ethiopia and Mozambique. *Energy, Sustainability and Society* 12, 23. https://doi.org/10.1186/s13705-022-00348-2

Hassan, Q., Algburi, S., Sameen, A.Z., Salman, H.M., & Jaszczur, M. (2023). A review of hybrid renewable energy systems: solar and wind-powered solutions: challenges, opportunities, and policy applications. Results in Engineering, 20. https://doi.org/10.1016/j.rineng.2023.101621

Heinrich-Böll-Stiftung. (2014). Nigeria's gas – wealth for all? Heinrich-Böll-Stiftung Nigeria. https://ng.boell.org/sites/default/files/uploads/2014/11/facts_about_nigerias_gas_0.pdf

IEA (2018). World energy outlook. https://www.iea.org/reports/world-energy-outlook-2018.

IEA Report (2015). Nigeria: electricity and heat for 2015. IEA - Report 1 March 2015. http://www.iea.org/statistics/statisticssearch/report/?country=Nigeria&product=electric/ityandheat

IEA (2015). *Energy technology perspectives: mobilizing innovation to accelerate climate action* 2015. https://doi.org/10.1787/energy_tech-2014-en

Ilenikhena, P.A., & Ezemonye, L.N. (2010). *Solar energy applications in Nigeria.* Retrieved from https://www.worldenergy.org/documents/congresspapers135.pdf

International Monetary Fund. (2013, January 23). Nigeria: 2012 Article IV consultation — Staff report (IMF Country Report No. 13/116). https://www.imf.org/external/pubs/ft/scr/2013/cr13116.pdf

International Energy Agency (IEA). *Africa Energy Outlook 2022*. Paris: IEA, 2022.

International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, World Bank, & World Health Organization. (2025, June 25). Tracking SDG 7: The Energy Progress Report 2025. https://www.who.int/publications/m/item/2025-tracking-sdg7-report

IRENA & AfDB (2022). Renewable energy market analysis: Africa and its regions. International Renewable Energy Agency, Abu Dhabi.

Iwayemi, A. (2008). *Nigeria's dual energy problems: policy issues and challenges. Energy Forum (4th Quarter),* International Association for Energy Economics, pp. 17-21

Jung, B., Park, J., Seo, D., & Park, N. (2016). Sustainable system for raw-metal recovery from crystalline silicon solar panels: from noble-metal extraction to lead removal. *ACS Sustainable Chemical Engineering* 4, pp. 4079-4083

Kiai, M.S., Eroglu, O., & Asifattahi, N. (2023). Metal-ion batteries: achievements, challenges and prospects. Crystals, 13, 7, 1002. https://doi.org/10.3390/cryst13071002

Kuhn, M. (2025). The 15 countries with the most days of pure sunshine ranked. Retrieved from climatecosmos.com/world-weather/the-15-countries-with-the-most-days-of-pure-sunshine-ranked/

Lawal, I. O., Bernard, O. A., Mustapha, M., Yakubu, A., & Ilemobola, O. (2025). The impact of solar energy financing on electricity generation in Nigeria. An ARDL approach. *Economics and Statistics Research Journal,* 16, 2, pp. 25-40. https://doi.org/10/5281/zenodo.14916729

Long, J., Lu, Z., Miller, P. A., Pongratz, J., Guan, D., Smith, B., Zhu, Z., Xu, J., & Zhang, Q. (2024). Large-scale photovoltaic solar farms in the Sahara affect solar power generation potential globally. Communications Earth & Environment, 5, 1, 11, https://doi.org/10.1038/s43247-023-01117-5

Madhuri, R. V. S., Said, Z., Ihsanullah, I., & Sathyamurthy, R. (2025). Solar energy-driven desalination: A renewable solution for climate change mitigation and advancing sustainable development goals. *Desalination,* 602, 10. https://doi.org/10.1016/j.desal.2025.118575

Mahmoudi, S., Huda, N., Alavi, Z., Islam, M. T., & Behnia, M. (2019). End-of-life photovoltaic modules: a systematic qualitative literature review. *Resources Conservation and Recycling*, 146, pp. 1-6.

Meng, Y., Nie, C., Guo, W., Liu, D., Chen, Y., Ju, Z., & Zhuang, Q. (2022). Inorganic cathode materials for potassium ion batteries. *Materials Today Energy* 25. https://doi.org/10.1016/j.mttener.2022.100982.

M-KOPA (2024). *Impact Report.* M-KOPA. https://m-kopa.com/impact.

Muye, H.M. (2016) Adoption of solar energy systems in remote and rural communities of Nigeria. *The International Journal of Science & Technology*, 4, pp. 23-28.

Nath, D. C., Kundu, I., Sharma, A., Shivhare, P., Afzal, A., Soudagar, M. E. M., & Park, S. G. (2024). Internet of Things integrated with solar energy applications: A state-of-the-art review. Environment, Development and Sustainability, 26, 10, pp. 24597-24652. https://doi.org/10.1007/s10668-023-03691-2

Nigeria Sovereign Investment Authority, NSIA (2024). NSIA & NSP sign joint venture agreement to co-invest in Nigeria's pioneer 20 MW on-grid solar hydro hybrid project

Nigerian Observer (2025, May 8). *24 federal tertiary institutions powered by solar - Education Minister.* Nigerian Observer. https://nigerianobservernews.com/2025/05/24-fed-tertiary-institutions-powered-by-solar-education-minister/

Ogundari, I. O., Akinwale, Y. O., Adepoju, A. O., Atoyebi, M. K., & Akarakiri, J. B. (2017). Suburban housing development and off-grid electric power supply assessment for north-central Nigeria. *International Journal of Sustainable Energy Planning and Management* 12, pp. 47-63

Ohunakin, O. S. (2010). Energy utilization and renewable energy sources in Nigeria. *Journal of Engineering and Applied Science*, 5, pp. 171-177.

Okereke, R.A., Ejekwu, T.B., & Ohamma, V.O. (2020). Achieving sustainable energy in Nigeria through photovoltaic (PV) technology: problems and prospects. *Global Scientific Journals,* 8, 3, pp. 1982-2006. https://www.globalscientificjournal.com

Olawoyin, I., & Ogunrinde, F. (2025, November 18). *INVESTIGATION: lead in their blood - how battery recyclers are poisoning Nigerians.* Premium Times.

Olawuyi, D. S. (2018). From technology transfer to technology absorption: addressing climate technology gaps in Africa. *Journal of Energy and Natural Resources* 35,1, pp. 61-84. https://doi.org/10.1080/02646811.2017.1379667

Olayungbo, D. O. (2019). Effect of oil export revenue on economic growth in Nigeria: a time varying analysis of resource curse. *Resources Policy* 64. https://doi.org/10.1016/j.resourpol.2019.101469

Osinowo, A. A., Okogbue, E. C., Ogungbero, S. B., & Fashanu, O. (2015). Analysis of global solar irradiance over climatic zones in Nigeria for solar energy applications. *Journal of Solar Energy*, Article ID 819397. https://dx.doi.org/10.1155/2015/819307

Oweibor, K., Diemuodeke, E.O., Briggs, T.A., & Imran, M. (2021). Power situation and renewable energy potentials in Nigeria-A case for integrated multi-generation technology. *Renewable Energy,* 177, 773-796

Oyebanji, A. O., & Adeleke, A. O. (2021). Solar Power Adoption in Nigeria: Opportunities and Barriers. *Renewable Energy Journal,* 14, 4, 213–225.

PPIAF (2024). *Noor Ouarzazate concentrated solar power plant, Morocco*. Retrieved from https://www.gihub.org/innovative-funding-and-financing/case-studies/noor-ouarzazate-concentrated-solar-power-plant/

PwC Nigeria (2017). *Rethinking Nigeria's proposed solar panel import policy*. Retrieved from https://www.pwc.com/ng/en/publications/rethinking-nigeria-proposed-solar-panel-import-policy.html

Rapu, C. S., Adenuga, A. O., Kanya, W. J., Abeng, M. O., Golit, P. D., Hilili, M. J., Uba, I.A., & Ochu, E.R. (2015, October). *Analysis of energy market conditions in Nigeria (Occasional Paper No. 55). Central Bank of Nigeria*. https://www.cbn.gov.ng/out/2017/rsd/analysis%20of%20energy.pdf

REA-NEP (2025). *FG launches Solar Power Naija Programme. REA-NEP*. Retrieved from nep.rea.gov.ng/posts/fg-launches-solar-power-naija-programme.html

Sambo, A. S., Zarma, I. H., Ugwuoke, P. E., Dioha, I. J., & Ganda, Y. M. (2014). Implementation of standard solar PV projects in Nigeria. *Journal of Energy Technologies and Policy*, 4(, 0, pp. 22–28.

Sodhi, M., Banaszek, L., Magee, C., & Rivero-Hudec, M. (2022). Economic lifetimes of solar panels. *Procedia CIRP*, 105, 782–787. https://doi.org/10.1016/j.procir.2022.04.124

Solar Power Naija (2025). *About Solar Power Naija. Rural Electrification Agency.* Retrieved from spn.rea.gov.ng

TRT *Global (2025). Nigeria strikes $200m deal to power rural areas with renewable energy*. TRT Global.

Ugulu, A. I. (2019). barriers and motivations for solar photovoltaic (PV) adoption in urban Nigeria. *International Journal of*

Sustainable Energy Planning and Management, 21. https://doi.org/10.5278/ijsepm.2019.21.3

Vanguard (2025, February 11). *FG to install ₦100bn solar mini-grids at UCH, UNILAG.* Vanguard. https://www.vanguardngr.com/2025/02/fg-to-install-%E2%82A6100bn-solar-mini-grids-at-uch-unilag/

World Bank. (2020). *Nigeria Electrification Project. Washington, DC*: The World Bank.

World Bank. (2018, November 12). *Bridging the skills gap is key for energy access, new jobs. World Bank Blogs*. https://blogs.worldbank.org/en/energy/bridging-skills-gap-key-energy-access-new-jobs

Zhang, P., Yue, C., Li, Y., Tang, X., Liu, B., Xu, M., Wang, M., & Wang, L. (2024). Revisiting the land use conflicts between forests and solar farms through energy efficiency. *Journal of Cleaner Production* 434, 139958. https://doi.org/10.1016/j.jclepro.2024.139958.

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There are no known financial competing interests to disclose

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Authors' Contributions

All components of the work were carried out by the author