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LOW-CARBON APPROACHES TO MEET NIGERIA'S ENERGY REQUIREMENTS IN ITS MIGRATION TO RENEWABLE ENERGY

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Abstract

Nigeria is at a critical crossroads: despite oil and gas earnings historically underpinning the economy, the nation endures persistent electricity shortages, significant dependence on diesel generators, and the social challenges posed by an unstable power supply. Recent policy and market indicators, such as the Energy Transition Plan (ETP), updated NDC commitments, and increasing investor interest in distributed renewable energy (DRE), present a strategic opportunity to expedite renewable energy deployment, enhance electricity access, reduce emissions, and foster resilient local economies. This study amalgamates technical, economic, institutional, and social viewpoints to delineate prioritised routes for Nigeria's low-carbon transformation. We evaluate the framework and limitations of the existing energy system by utilising evidence from scholarly research, national policy frameworks, and international assessments. We analyse the potential and deployment options for renewable resources at both utility and decentralised levels, explore financing and institutional challenges, and propose specific policy and implementation strategies. The analysis indicates that Nigeria's renewable energy resources—solar, hydro, biomass, and localised wind—are underutilised due to ongoing system instability, financial deficiencies, and gaps in policy implementation. Decentralised systems, including solar household units, mini-grids, and hybrid solutions, constitute the most economical approach to electrification and less dependence on diesel. Attaining scale necessitates the persistent execution of policies, tariff reform, blended finance, and the enhancement of skills, while safeguarding social rights and facilitating an equitable transition for regions reliant on fossil fuels. We conclude with a strategic *plan and research agenda to synchronise climate targets, investment streams, and equitable considerations in Nigeria's energy future.*

1. INTRODUCTION

Nigeria, the most populous nation in Africa and its largest economy by GDP, plays a crucial role in influencing both continental development paths and the global transition from fossil fuels. Notwithstanding its substantial hydrocarbon reserves, particularly oil and natural gas, the country persists in facing an inconsistent electricity supply. The national grid persistently fails to meet demand, forcing households and businesses to rely on kerosene, diesel and petrol generators for their daily energy requirements. This contradiction of resource abundance coupled with enduring energy poverty highlights the simultaneous challenges and prospects associated with Nigeria's transition to renewable energy (Aliyu, 2015; EIA, 2023).

Nigeria has established ambitious frameworks for climate and energy transition. The Energy Transition Plan (ETP) outlines a trajectory towards achieving net-zero emissions by 2060, supported by long-term low-emission development strategies (LT-LEDS) and revised Nationally Determined Contributions (NDC) pledges from 2021, which incorporate conditional mitigation targets linked to international financing and assistance. Although these frameworks indicate ambition, substantial implementation challenges persist. Facilitating a fair and expedited transition necessitates strategies that connect Nigeria's renewable resources—solar, hydro, biomass, and decentralised mini-grids—with accessible financing, institutional reforms, and protections for communities reliant on fossil fuel industries (Energy Transition Budget analysis, 2023). This article integrates contemporary facts and policy discussions to recommend feasible transition pathways for Nigeria. It underscores decentralised renewable energy (DRE) as the most expedient and economical solution for electrification, while simultaneously accentuating the incorporation of utility-scale renewables into an enhanced infrastructure. Mitigating political economy restrictions and utilising creative financing are essential for realising a scalable, inclusive, and resilient energy transition (Akinyele et al., 2015; Chanchangi et al., 2023).

2. APPROACHES USED IN THIS STUDY

This study offers a comprehensive synthesis derived from various evidence sources: (a) peer-reviewed research on Nigeria’s energy sector and renewable resource evaluations, identified through systematic searches in Scopus, Web of Science, and Google Scholar; (b) national policy frameworks and planning documents, including the Energy Transition Plan (ETP), LT-LEDS, and updated Nationally Determined Contributions (NDCs); (c) reports and technical papers from international organisations such as the IEA, IRENA, World Bank, and EIA; and (d) credible media coverage of recent developments in the sector, including grid failures, subsidy reforms, and financing initiatives. Priority is given to empirical research and reputable statistics (e.g., World Bank and IEA datasets) to guarantee credibility and policy significance.
The book aims to offer a policy-oriented synthesis that integrates academic analysis, policy documentation, and international evaluations, rather than producing fresh primary data. A primary constraint is the fluidity of Nigeria's energy and policy landscape, characterised by fluctuating financial commitments and changing deployment objectives, which creates ambiguity in forecasting long-term results. The suggestions emphasise the need for institutional fortification, governance reforms, and adaptable policy frameworks capable of enduring market volatility and

political changes, while promoting an inclusive and sustainable renewable energy trajectory (IRENA, 2022).

3. The current state of Nigeria's energy system

3.1 Primary Energy Composition and Electricity Sector Framework

Nigeria's energy sector is predominantly reliant on fossil fuels. Oil constitutes the foundation of export revenues and powers transportation and small-scale electrical production, whilst natural gas is progressively recognised as a domestic transition fuel and a vital industrial feedstock. National statistics and worldwide energy profiles indicate that the country has extensive proved gas reserves, and gas-fired power has traditionally comprised a substantial portion of electrical generation. Nonetheless, persistent impediments such as pipeline outages, supply deficiencies, and plant.

Failures, vandalism, and inherent transmission deficiencies continuously diminish actual output. Despite the official documentation of installed generation capacity in the tens of gigawatts, the actual accessible supply significantly lags behind this potential. Operational inefficiencies, along with institutional and infrastructural limitations, result in inadequate per-capita electricity supply. Consequently, homes and enterprises throughout Nigeria heavily depend on decentralised diesel and petrol generators, leading to elevated energy expenses, air pollution, and susceptibility to fluctuations in fuel prices (IEA, 2024).

3.2 Access to Electricity and Reliability

Global statistics and IEA assessments underscore ongoing deficiencies in universal power access and the underutilisation of the national grid, particularly in rural areas. Data from the IEA and World Bank reveal that access improvements in Nigeria are inconsistent: urban families see comparatively greater connection rates, whilst rural communities are markedly underserved. The discrepancy is exacerbated by frequent grid failures and widespread blackouts, which diminish trust in centralised supply. The grid's instability compels extensive dependence on expensive generator fuel, escalating production costs for businesses and households, so undermining overall economic competitiveness (World Bank country due to access to electricity) (NEP/REA, 2023; ETP, 2023).

3.3 Institutional Frameworks and Historical Reforms

Nigeria's electricity system has undergone continuous reform initiatives, especially since the early 2000s, focusing on the privatisation and unbundling of generation, transmission, and distribution to entice private investment and enhance efficiency. However, ongoing institutional deficiencies, tariff shortfalls, and accrued liabilities have consistently eroded investor trust and constrained industry transformation. Recent initiatives, including the formation of the Rural Electrification Agency (REA) to promote decentralised renewable energy and mini-grid implementation, constitute essential components of current transition efforts. For these initiatives to be effective, policy frameworks must equilibrate federal and state responsibilities, guarantee transparent and competitive procurement processes, and tackle the economic sustainability of changes (UNFCCC/NDC Partnership, 2023).

4. Potential of renewable resources and present implementation

4.1Solar photovoltaic (PV) technology

Nigeria possesses some of the greatest sun radiation levels in Africa, establishing solar photovoltaics (PV) as its primary renewable energy resource. Deployment options encompass extensive solar farms linked to the grid, rooftop photovoltaic systems catering to commercial and industrial clients, and an ever-expanding decentralised market of solar home systems (SHS) and community mini-grids. In recent years, the adoption of decentralised solutions has intensified, propelled by private sector innovation and donor-supported initiatives, with the Rural Electrification Agency (REA) significantly pushing mini-grid and solar home system (SHS) programs. However, numerous challenges remain: dependence on imported panels and system components, restricted access to affordable local financing, significant capital expenditures for utility-scale projects, and the technical difficulties of incorporating variable solar generation into an already vulnerable grid without additional investments in storage and modernisation (Pendleton et al., 2012; EIA, 2023).

4.2 Hydropower and Small Hydroelectric Systems

Hydropower in Nigeria has a longstanding history, with large-scale dams augmenting the grid, although constrained by environmental and societal factors, sedimentation, and fluctuation. Small hydro (run-of-river and mini-hydro) can be efficient in particular river basins and for localised micro-grids. Nonetheless, substantial dam projects necessitate meticulous environmental and socioeconomic evaluations, as well as money, and can require years for completion. Hydropower is essential for the seasonal stabilisation of renewable energy sources but is hindered by climate unpredictability. (EIA, 2023).

4.3 Biomass and Bioenergy

Biomass resources, such as crop leftovers, organic municipal waste, and dedicated energy crops, constitute a significant renewable energy alternative, especially for rural electrification and combined heat and power in agricultural processing centres. To optimise advantages, bioenergy efforts must confront sustainability difficulties, including food-fuel rivalry and land-use pressures, while using efficient conversion techniques such as gasification and biogas systems. Despite its current limited application in Nigeria, bioenergy presents potential within circular economy models by converting waste streams into usable energy. Analysis of the Energy Transition Budget 2023

4.4 Wind Energy

wind energy in Nigeria is significantly site-dependent, with practical potential primarily located in coastal areas and certain northern regions where wind speeds are advantageous. In contrast to solar energy, wind energy implementation has been minimal due to inadequate resource mapping, elevated infrastructure expenses, and governmental preferences favouring solar expansion. However, the integration of wind energy with solar and storage systems offers potential for hybrid solutions in regions where wind conditions are conducive to commercial-scale investment (Mohammed et al., 2013; Mwikamba, 2024).

5. POTENTIAL POF RENEWABLE ENERGY UTILISATION IN NIGERIA

Renewable energy possesses significant potential in Nigeria and might address substantial energy deficiencies in rural regions, especially in northern Nigeria. The magnitude of prospects is only now becoming evident as novel grid technologies, such as concentrated solar power, emerge as challengers to traditional power generation. Technological advancements indicate that solar power, when well financed, has the potential to revolutionise household energy requirements. Affordable compact lighting items priced below $30 enable low-income households to benefit, however funding even minimal capital expenditures continues to be a challenge at all levels. Advancements in lighting provide potential enhancements in meeting additional requirements, owing to ongoing gains in efficiency and cost-effectiveness.

The magnitude of renewable energy potential much exceeds the awareness of the public and politicians. Recent studies reliably estimate Nigeria's concentrated solar thermal power potential to exceed 427,000 MW. Current electricity generation levels of approximately 5000MW satisfy merely a portion of demand, and renewable energy could assume an increasingly significant role. Extensive renewable energy generation has the potential to be transformative, yet small-scale consumer and household systems could provide energy autonomy for most individuals currently lacking consistent electrical access.

The experiences of a limited number of renewable energy providers in Nigeria over the past decade are essential for the development of sustainable markets. For the sector to advance, both practitioners and government must assimilate lessons on proper adaptation, service, installation, and efficiency in emerging technologies. Failing to integrate this experience poses a significant risk of perpetuating the underperformance that has led to near market failure in recent years. Significant education of consumers and officials is necessary to transform existing negative opinions into informed judgements regarding energy options.

The unit cost of renewable energy ($0.26–0.50/kWh) significantly exceeds that of grid electricity ($0.10–0.15/kWh), which primarily accounts for the implementation of subsidies and feed-in tariffs in numerous countries. A significant portion of international planning and incentives is centred on climate change obligations and trends, wherein the swiftly decreasing cost of renewable energy is projected to render it competitive without subsidies within ten years. In Nigeria, the immediate competitiveness of renewable energy is more probable due to the dependence on generators and kerosene, which elevates the actual cost of energy requirements in numerous regions to above $0.50 per kilowatt-hour.

Financing for renewable energy presents a significant challenge, as the majority of expenses are borne upfront during installation. The elevated borrowing costs in Nigeria, characterised by interest rates over 20 percent, serve as a significant deterrent to energy investments that may recover expenses within relatively brief durations (about 1–3 years). This issue affects all strata—ranging from impoverished families attempting to secure $30 for essential lights to households and enterprises requiring substantial investments amounting to thousands of dollars.

Significant advancements in energy efficiency and the affordability of renewable energy sources have resulted in a substantial reduction in the capital required for essential applications. The adaptation of renewable energy for water boreholes, lighting, refrigeration of medical supplies, and IT applications in rural regions has swiftly become more economical. Capital investment is necessary. However, expenses have frequently decreased by over 75 percent in the past five years. Essential measures remain necessary to connect capital, market development, and reliability; yet, international expansion indicates that these measures could facilitate rapid transformations. Comprehensive reforms are essential for Nigeria to achieve its renewable energy potential. These modifications necessitate simultaneous implementation and sufficient resources. The subsequent important recommendations underscore the imperative for a comprehensive approach to transformation.

6. PRINCIPAL RECOMMENDATIONS

Formulate cohesive strategies for renewable energy planning and investment. The federal government must enhance its current activities by formulating a comprehensive renewable energy strategy and implementing a substantial increase in funding for research, market development, and regulation of renewable energy.

Facilitate incentives for the adoption of renewable energy

The government should contemplate incentives, potentially via a feed-in tariff, for at least one significant trial project of solar thermal power generating in northern Nigeria.

Guarantee enough and economical capital funding

Systematic expansion of low-interest capital finance for renewable energy is essential, with capital availability increasing in tandem with industry growth.

Enhance public comprehension of renewable energy

Stakeholders in the renewable sector and government must substantially spend in public education to enhance consumer and policy decisions and to dispel prevailing biases against the industry.

Foster cooperation between renewable energy developers and politicians

Policymakers and renewable energy stakeholders must collaborate to establish optimal service practices in rural regions, especially with education, healthcare facilities, and water supply.

Instruct on energy use and efficacy

Energy consumption, especially energy efficiency and renewable energy, must be integrated into the education system promptly to influence public behaviour and enhance engagement in the burgeoning renewable energy sector.

7. POTENTIAL FOR SUSTAINABLE ENERGY ADVANCEMENT

The prevailing view of renewable energy in Nigeria primarily emphasises solar energy, with occasional reference to wind power. Renewable energy has a rather brief history in Nigeria, particularly in the public consciousness. Nevertheless, hydropower-derived renewable energy has been fundamental to Nigeria's grid electricity generation since the 1960s. Until recently, the Kanji and Jebba Dams (1300MW) constituted around 50 percent of Nigeria's reliable power sources, having since been surpassed by gas power stations, whose functionality is limited by the deteriorating national system and inconsistent gas supply.

Power supplies in Nigeria are severely constrained: grid energy is accessible to just approximately 50 percent of the population, and even then, it is inconsistent. This has been essential to the initial growth of renewable energy in Nigeria. It has created a significant motivation to seek a more reliable solution that does not incur the continuous financial burden linked to the elevated expenses of electricity from the 'stand-by' generators, which have become the primary power source for numerous essential rural services.

The people and authorities in Nigeria have a limited understanding of wind and solar energy. The achievements are significantly less recognised than the deficiencies, which have been conspicuously evident in the unsuccessful solar street-light initiatives scattered throughout Nigeria's major urban areas. In popular perception, solar power plants have predominantly been synonymous with numerous unsuccessful government initiatives—evidence of inadequately implemented technology linked to favouritism and corruption.

Nevertheless, the achievements of renewable energy in Nigeria should prompt reflection among its detractors. The modest yet expanding array of solar energy initiatives that have been diligently executed have provided significantly improved service stability than analogous interventions. They also provide the most elusive benefits in rural Nigeria—feasible long-term sustainability. Global advances and enhancements in affordability regarding vaccine storage, rural water supply, and illumination for low-income populations are advancing rapidly and can be adopted for Nigeria.

Renewable energy must not be regarded in isolation. Advancements in the subject are intrinsically linked to enhanced energy efficiency, which has been essential in reducing costs and enabling new applications. In comparison to the current expenses of electricity in Nigeria, predominantly from generators, there is a compelling argument for significant interventions. This contrasts with other developing nations that possess a steadier grid electrical supply.

This article aims to investigate the well-known yet inadequately comprehended domains of solar power and energy efficiency, together with their consequences and prospects for Nigeria. It pertains to the power sector, emphasising some deficiencies in the proposed quick privatisation, along with the related hazards for individuals in rural areas and those with low incomes.

The coverage of wind, hydro, and biomass energy in this article is minimal—not because to a lack of promise, but because additional research is required before they can be effectively evaluated for Nigeria. The brief discourse on energy policy and the recent scenario analysis conducted by a World Bank team underscores the unexpectedly robust potential for low-carbon energy expansion in Nigeria. This pertains to the possibility for extensive growth of renewable energy, especially in northern Nigeria.

8. SPECIALISED APPLICATIONS FOR RURAL NIGERIA

Since the 1990s, numerous investigations on renewable energy in Nigeria have predominantly focused on photovoltaic (PV) solar power. This section highlights four applications of solar electricity that serve as models, demonstrating essential lessons on how renewable technology can be optimally tailored to local requirements. The models created are the culmination of years of incremental enhancements by many organisations or collaborations, leveraging both experience and emerging technology. Due to spatial constraints, only a fraction of the evolution can be adequately represented here, and it is crucial to acknowledge the contributions of innovators—both socially progressive enterprises and NGOs—that have consistently endeavoured to showcase these new technologies in authentic rural settings.

8.1 Solar Water Pumping:

The availability of potable water has been a persistent issue in Nigeria, with many areas depending on water extracted from privately owned boreholes or those funded or established by the government. In each instance, there has been continuous instability due to the expenses associated with operating boreholes when grid electricity is either inconsistent or completely unavailable. Boreholes in rural regions typically depend on generators, which are costly to maintain and operate. Failures in water supply within relatively Brief time intervals are prevalent in numerous regions of the country, especially the Niger Delta.

The Niger Delta Wetlands Centre (NDWC) has been doing experiments with solar-powered water boreholes since the mid-1990s. A primary motivation is to directly contest the region's reputation for being 'too overcast' for efficient solar power use. The Centre has successfully showcased model water boreholes based on various fundamental concepts and has provided concrete proof refuting the "too cloudy" argument.

The architecture of the NDWC borehole water supplies is predicated on simplicity throughout all phases. Numerous solar systems include a combination of panels, charge controllers, batteries, and inverters to gather, store, and utilise solar-generated electricity. Each important component has specific maintenance requirements and susceptibility to failure. This presents a considerable difficulty in an environment characterised by inadequate planning and resources for maintenance, coupled with a limited understanding of emerging technologies such as solar power.

The NDWC solution aimed to reconcile conflicting challenges to achieve a design that was both straightforward and resilient. By selecting a system capable of delivering adequate drinking water during daylight hours, they chose a direct current (DC) system that obviated the necessity for batteries and inverters. This promptly eliminated two components that were the most costly and most susceptible to failure. The system compensates by monitoring anticipated overall water consumption, adjusting tank and daytime pumping and storage capacity accordingly.

The system possesses several well-established strengths:

a) Investment in high-quality components yields exceptional durability.
b) Maintenance expenses are sufficiently cheap to be feasible in rural regions.
c) There is a persistent decline in the costs of key components, chiefly solar panels.
d) The efficiency of both pumps and panels persists in enhancing.

a) Nonetheless, there are also significant difficulties that have been emphasised: Low maintenance does not equate to maintenance-free; some professional assistance still necessary.
b) Preliminary capital expenditures remain considerably more than those of generator/grid systems.

c) Alignment of capacity requirements with demand management—systems will operate solely within their storage capacity for a 24-hour duration and will not replenish overnight.

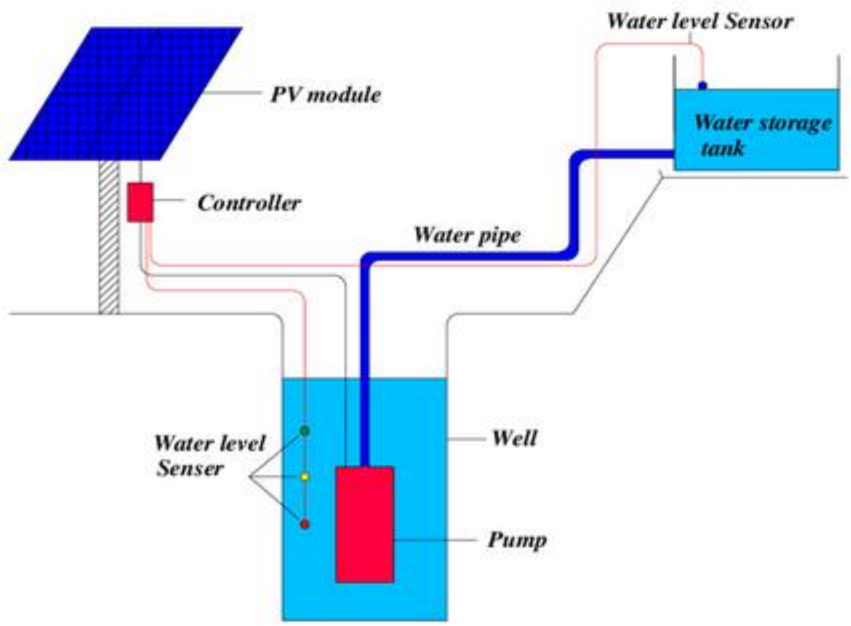

Figure 1. Basic elements of a direct current solar water-pumping system

The efficacy of this technology is well established in one of the least sunny regions of Nigeria; yet, some aspects require attention for the system to achieve its maximum potential. Following a phase marked by numerous unsuccessful installations, the Niger Delta Development Commission seems to have embraced the streamlined design initially advocated by NDWC as the regular procedure in rural locales. Nevertheless, some government agencies and departments persist in financing generator-based initiatives (notwithstanding their regularly elevated failure rate) or inadequately planned solar installations. There is less investigation into the 'right-sizing' of drinking-water supply designs to meet community requirements, with a preference for singular huge hubs irrespective of actual necessity.

Given the diminishing payback periods, wherein savings on fuel expenses completely offset the additional capital expenditure within 18 months to 3 years, it is evident that the technology need to be adopted as standard in 'off-grid' or inadequately serviced areas throughout Nigeria. This decision would also validate the modest investments required for research to enhance the alignment of system size with needs, as well as the comparatively low expense of regional technical assistance.

8.2 Small solar illumination devices

Similar to other solar uses, experiments in solar illumination in Nigeria have been conducted for some years, however they have achieved only minor success at best. The objective of the few projects observed by the author has been to offer illumination options to kerosene lanterns and small generators for homes with relatively low incomes. The initial systems utilised direct current lights powered by diminutive solar panels, supplemented by batteries capable of supplying energy to minor devices like radios. They seem to have experienced the complete spectrum of obstacles faced by early solar trials in Nigeria: insufficient beneficiary engagement, difficulty in maintenance and supply chains, comparatively high short-term costs, and uncertainties over the ambitions of beneficiaries with diverse demands. Nigeria was not significantly exposed to the initial solar lanterns, which commenced at prices exceeding $100 and exhibited performance considerably inferior to contemporary models.

Over the past three years, there has been a significant rise in lighting alternatives, cost-effectiveness, and dedication from developers targeting various regions of Africa, accompanied by noteworthy innovations within Nigeria. This is predicated on the advancement of economical and durable LED lighting accessories, improved battery alternatives, and significant reductions in the cost of solar panel components. The new devices are diminutive, with batteries and LED lifespans measured in years, with most batteries being 3–5-year lithium variants, and portable solar panels smaller than a shoebox.

Figure 2. Illustrations of small solar illumination systems.

The latest generation of products currently emerging in the market is rapidly establishing a comprehensive array of options for households and small enterprises—from economical kerosene lamp alternatives priced as low as $15 retail to high-end systems that may cost up to $500, providing enhanced illumination across multiple rooms while also charging laptops and mobile phones.

Targeting of design to specific prospective needs is developing. One concept, in collaboration with the Federal Ministry for the Environment, is primarily aimed at tiny hairdressing salons, which exhibit a clear minimal power requirement where designs can rival a small generator. The World Bank's 'Lighting Africa' program, which fosters the development of this new generation of products, has sought to tackle quality concerns by implementing a comprehensive quality assurance initiative that instills a significant level of consumer confidence regarding reliability. Section 3.1 of this paper provides a comprehensive analysis of technological advancements and their possibilities.

In Nigeria, solar illumination for families has transitioned from a marginal experiment plagued by substantial cost challenges to one with considerable potential. International initiatives fostering

collaboration and innovation have led to significant growth for small enterprises in various regions of Africa, alongside a nascent yet increasing recognition of the market potential and advantages in Nigeria.
The primary potential beneficiaries of this new generation of products in Nigeria are the substantial segment of the estimated 70 million Nigerians lacking access to grid electricity. The potential for dependable nighttime illumination for households and small enterprises, without a continuous financial burden, could be transformative for numerous individuals. The new items are experiencing a moderate introduction in Nigeria.

Despite significant advancements and substantial reductions in cost for household products, they nevertheless necessitate marketing, supply chains, product support, and alignment with customer capabilities and requirements. Various countries have implemented several different strategies to tackle these difficulties, ranging from microfinance to hire purchase schemes. These solutions are feasible in Nigeria, however they have frequently demonstrated greater challenges compared to other low-income nations.

If the current evaluations of these items are accurate—that they provide transformative improvements over their lifespan—then the constraints revert to financial considerations (refer to Section 6) and the establishment of a modest consumer industry. The significant simplification and cost reduction of solar lighting products may facilitate the emergence of modular combinations of small solar devices in Nigeria, allowing for customisation and upgrades based on needs, budget, and evolving household circumstances. Importantly, compact solar devices have attained a status as modest yet resilient assets that are reasonably portable and possess a considerable lifespan.

8.3 Refrigeration (vaccines and medical supplies)

Initial solar power uses in refrigeration fulfil a critical health requirement, similar to solar-powered water pumps. Nonetheless, both apps provide economical home alternatives as a primary objective for a significant majority of Nigerians. For several years in Nigeria, numerous companies have been implementing solar-powered vaccine refrigerators capable of providing consistent service in rural regions where resources for fuel and maintenance are typically inadequate. KXN Nigeria received an Ashden Innovation Award in 2008 for the deployment of solar-powered refrigerators in central and northern Nigeria.

Since its inception in 2002, the company has reported the installation of 767 refrigeration units at health institutions pivotal to the campaign against polio eradication. The refrigerators were tiny and utilised merely 60 watts of electricity due to enhanced insulation. In 2009, KXN approximated the costs per system, encompassing solar and refrigeration, to be approximately $11,000. This encompassed expenses for a specialised firm functioning in a secluded region. A comparable rural generator-based system would have incurred a minimum cost of $2500–3000, while the long-term fuel expenses would be exorbitant to maintain the requisite stable temperatures for storage. The expense associated with system failure, or depleting fuel, reaching as much as $5400 for an entire batch of medicine housed in a single refrigerator, underscores the significant motivation for a reliable power source.

Interviews with other consultants revealed successful implementations of regional maintenance contracts, when a service provider managed a designated area encompassing many states for any arising faults. This was coupled with training on-site personnel to manage fundamental issues and was considered highly successful at the time. The burden on service providers was minimal due to the excellent reliability of systems and the ease of resolving fundamental issues via a remote help desk. However, cost was evidently a constraint confining this technology to a specialised use, necessitating a complete system of panels, batteries, and inverters.

Recently, a UK business, Surechill, has exhibited significant advancements in integrating enhanced design and efficiency. The product is a refrigerator capable of enduring temperatures of 43°C for seven days without any power source, requiring merely a 350W solar panel array (slightly more than two standard panels) for fully off-grid functionality. Similar to advancements in other sectors, the efficiency improvements in this context significantly diminish the requirement for battery and inverter components. As a result, this has led to a significant reduction in total expenses. Even at introductory costs, Surechill solar units are projected to be approximately one-third the cost of previously installed systems.

Similar to the instance of IT centres (Section 2.4), the efficiency improvements in solar-powered refrigeration prompt the inquiry of whether numerous advantages could be attained with a smaller petrol or diesel generator. The inclusion of a reliable, well-maintained generator would reduce short-term expenses; however, the capital investment necessary for a solar alternative has significantly decreased to a more manageable level. Solar alternatives would incur higher initial costs; however, they would prove more economical over time in comparison to a generator. A solar system necessitates significantly lower expenditures than in previous years; yet, the reliability and little daily inputs needed for a high-quality system continue to be advantageous for solar electricity.

Solar energy remains a significant contributor to the reliability of refrigeration and supply networks for vaccinations. Interviews with solar practitioners and health organisations reveal lessons that seem to have been overlooked over time. The failure rate of refrigeration systems is considerable, accompanied by ongoing maintenance concerns. Some issues serve as reminders that solar systems are not the sole components necessitating maintenance, as fundamental refrigerator upkeep and replacement are evident concerns. However, instances of solar component failures due to trivial factors (such as dust or foliage on panels) exist, and prior regional support systems have not been sustained. There is a clear necessity to integrate insights from previous years and to leverage emerging technology.

Innovations in technology and fundamental enhancements outside the solar sector—such as more efficient commercially accessible refrigerators and freezers—indicate a need for a comprehensive reevaluation. Several years ago, refrigeration for middle-income households was considered excessively costly. With the advent of accessible freezers providing a fundamental 'remain cold' capability for several days, it is imperative to reassess and elucidate the potential of tiny home-solar systems to the public. The breakthroughs achieved by organisations at the forefront of inventive design indicate that even greater benefits are likely to emerge within the relatively brief periods typical of progress in renewable technology.

8.4 Off-grid IT Centres

The IT sector exemplifies the advancements in alternatives for systems powered by renewable energy. A persistent aspiration exists to enhance access to information technology and the internet for Nigerians, especially for individuals with limited incomes residing in rural regions. The anticipated advancements in social inclusion, education, information access, and governance are regarded as crucial for mitigating inequality disparities in Nigeria.

Nonetheless, the challenges associated with sustaining IT centres, especially in rural regions, closely resemble those encountered in other minor rural infrastructure initiatives, exacerbated by the delicate nature of the technology. The expenses associated with generating power, equipment maintenance, damage from power surges, and general deterioration have resulted in a significantly elevated failure rate over a little duration. In 2006, an NGO managing the STAND governance project in the Niger Delta explored an off-grid solar solution utilising standard personal computers, but the estimated cost was exorbitant—approximately $120,000 for energising a rather modest centre.

Three years later, the succeeding project manager, SDN, who took over the project, chose to implement a pilot utilising newly built low-energy computers specifically engineered for challenging rural environments. Aleutia PC systems have diminished the energy consumption of a base unit to approximately 9W, down from 200–300W in 2006, while flat-screen displays have more than half their energy usage. Despite the absence of recent reductions in solar-panel prices, the expenses for a comprehensive centre decreased by more than 75 percent to below $25,000, while the durability of the computers permitted a five-year warranty.

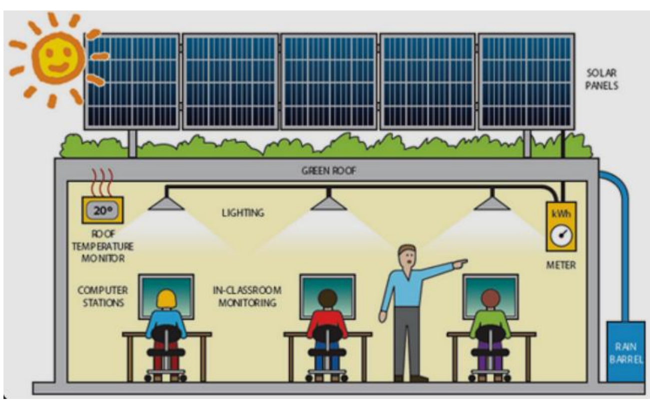

Figure 3: The Computer Classroom System

Numerous IT centres employing identical technology exist in various regions of the Niger Delta, along with a limited number of pilot projects in other areas of the country. The capital and energy requirements of systems have decreased, enabling the installation of stand-alone systems centred on a single modest solar panel. However, similar to other domains of solar technology, broader adoption has been constrained.

The potential of solar combinations in information technology appears more unequivocal than in other domains. Ongoing improvements in computing efficiency indicate that meticulously built IT centres and classrooms could operate on minimal solar installations. Meticulous hardware selection may result in less maintenance and potentially decrease the required components. Schools have the opportunity to incorporate this into a good educational exercise regarding energy consumption and renewable resources.

Numerous states and agencies are allocating substantial funds to establish IT centres for educational institutions in both urban and rural regions. These projects frequently experience premature failure due to insufficient initial contracting and inadequate upkeep. The integration of solid-state technology with solar energy provides solutions to numerous prevalent issues. Nonetheless, advancement will necessitate a degree of public-sector dedication to the technology and several ancillary measures. The ongoing advancement of solar lighting should encompass a comprehensive integration of efficient, durable, and cost-effective components to provide solutions of exceptional value. The comparison of efficiency for laptops and tablets is clear, as premium products are already accessible internationally. In Nigeria, there is a necessity for enhanced integration of resilient computing, cost-effective batteries, and precisely calibrated solar energy.

8.5 Insights from Initial Pilots

All pilots and initial experiences in Nigeria exhibit clear technical proficiency and unrealised potential. A considerable aspect of this is undoubtedly related to financing and market development; yet, it is important to emphasise the shared factors connecting various applications. These include:

- Polished design, prioritising streamlined combinations of securely shielded components that are, when feasible, durable and solid-state.
- Advancements in technology and solar efficiency persist in rendering solar items and systems increasingly economical and dependable.
- An economically viable maintenance capacity and fundamental training for end users are crucial for sustainable performance.
- The education of government and agency managers regarding development budgets is likely essential for market growth.
- Access to foreign applied technologies should be prioritised to expedite their adaptation for usage within Nigeria.

9. IS THERE A PROMISING FUTURE FOR RENEWABLE ENERGY IN NIGERIA?

Notwithstanding the sluggish inception of dependable renewable energy technologies in Nigeria, there exists cause for optimism regarding their potential. This section examines significantly varied tiers of the same technology, ranging from consumer-grade items to grid-scale generation. This section's examples aim to illustrate developments and reflect only a portion of the ongoing changes. Recent advancements indicate that the foundational aspects and array of renewable energy alternatives in Nigeria are far more robust than acknowledged by the majority of policymakers and the public, necessitating an urgent response to the challenges posed by market and financial constraints.

9.1 Technology for Consumer Products

The technological advancements outlined in the pilots and specialised project applications of Section 2 are occurring more widely and at an accelerated pace. The promotion of solar lanterns and domestic illumination for low-income individuals underscores the rapidity of development. In

2009, development agencies and niche enterprises actively marketed the technology with considerable excitement. The price of an individual lantern ranged from \$100 to \$500, making it challenging to rationalise for low-income families.

In just three years, by 2012, the technology has solidified around significantly reduced costs, nearly indestructible LED lights, and battery longevity that can authentically be asserted to be between 3–5 years, with ongoing enhancements. The price of entry-level products is currently approximately \$25, and the payback period for the capital expenses of these products, in comparison to the daily expenditure on kerosene lanterns, is now credibly said to be significantly less than one year, thereby rendering a variety of new financing alternatives viable.

Figure 4. Low-cost solar-powered illumination Devices

Observations: LED lights have prolonged longevity and enhanced durability. Lithium batteries: offering warranties of up to five years.

The significant advancements in lighting stem from innovations in various facets of the final product:

- enhanced quality and cost of solar panels
- complete transformation in illumination technology
- novel generations of cost-effective lithium batteries
- removal of components—where independent systems can operate straight from batteries without inverters or replacement lights.

Moreover, a significant alteration in the market has occurred—the introduction of diverse competitive items with varied power levels, offering households a selection. Households utilising rudimentary kerosene lanterns undoubtedly experienced a lighting deficiency, rendering them unable of performing essential duties. The latest generation of solar illumination devices provides substantial enhancements over kerosene lanterns, as well as compact stand-alone systems appropriate for permanent installation in small residences. In the capacity of products As markets enhance, we can anticipate additional advancements in aligning inexpensive lighting solutions with genuine requirements.

Significant advancements in price are being achieved by removing supplementary requirements—expensive and energy-intensive inverters are unnecessary, and recent batteries exhibit enhanced reliability and portability. The concurrent enhancement of lighting product efficiency and solar energy has significantly increased product accessibility. The prospect of addressing additional needs in a comparable manner seems to be expanding. There are enhancements in the efficiency of a substantial array of products utilised in households and small-scale services, with electronic products exhibiting notably robust and constant advances in efficiency.

Most households and small companies in Nigeria currently rely on small computers, LED televisions, radios, and lighting powered by petrol or diesel generators. Petrol generators incur expenditures exceeding 50 cents per kWh, far surpassing the expenses associated with unsubsidised solar power throughout its lifespan.

9.2 Extensive Generation Potential of Solar Thermal Energy

Nigeria's considerable oil and gas reserves, along with extensive coal deposits, have resulted in less consideration for renewable energy possibilities in power generation. All pilots mentioned have concentrated on independent designs, with merely a few isolated efforts to investigate village-sized installations. Figure 3.2, depicting the global intensity of solar radiation, was utilised by Lumina Decision Systems in a framework for solar thermal power in Nigeria for a World Bank research. It positions Nigeria comparably to Spain, the foremost developer of solar thermal power outside the United States. The southern and eastern regions of Nigeria see prolonged durations of substantial cloud cover, considerably diminishing solar radiation intensity. This does not imply that solar electricity is unfeasible in southern Nigeria. Solar power involves generally high-energy procedures and requirements, utilising mirrors and light concentration, however solar PV panels can endure a broader spectrum of daily conditions and have been effectively shown in southern Nigeria.

Solar thermal power exemplifies an emerging renewable energy technology characterised by a brief history yet accompanied by significant confidence on its trajectory and eventual potential. In a little period, it has addressed two significant challenges: substantially reducing generation costs and creating effective energy storage capable of providing electricity overnight. Solar energy derived from photovoltaic panels has the inherent limitation of generating power solely during daylight hours, while nighttime reliance is confined to the comparatively costly alternative of batteries.

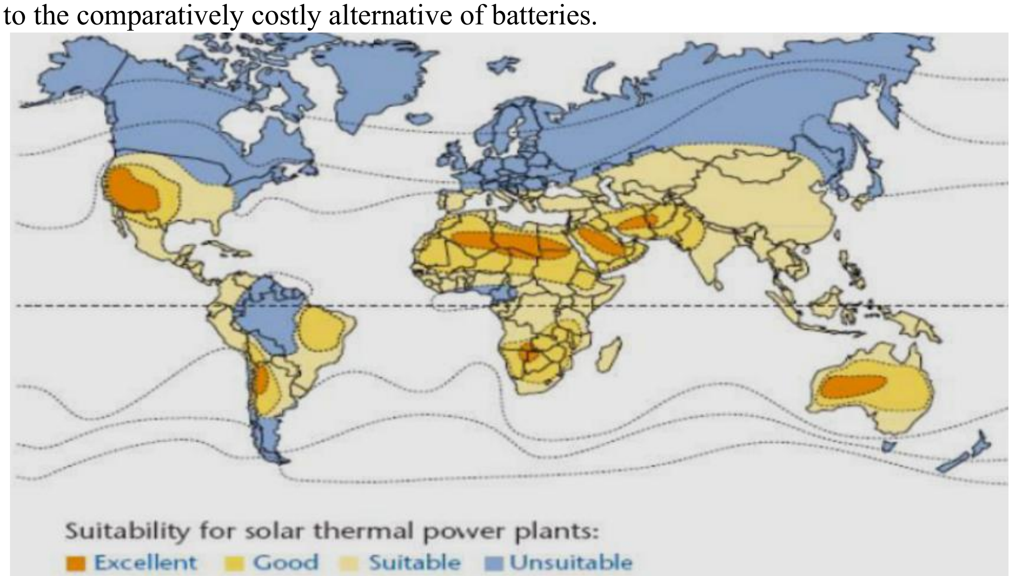

Figure 5. Worldwide prospects for solar thermal power facilities
(https://www.researchgate.net/publication/311695640_Forecasting_transition_electricity_solar_energy_from_Mena_to_Europe/figures?lo=1)

Thermal solar utilises highly heated salts to serve as an energy source for the turbines that generate consistent and continuous power throughout the day. The technology is sufficiently nascent that its pricing is still determined by few data points and an anticipated decline in expenses. The confidence in the technology has already resulted in the remarkable Desertec project in the Sahara Desert. European enterprises have ample confidence in price patterns, enabling them to strategise for a substantial installation throughout northern Africa, facilitating high-voltage power transmission to Europe. Initial investments above $1.5 billion have been secured in Morocco, with the expenses associated with next-generation transmission deemed 'small' supplementary charges.

The World Bank's analysis of Nigeria estimated that designating 5 percent of eligible land in central and northern Nigeria for solar thermal might yield a theoretical power production capacity of 42,700 MW. In actuality, the global installed capacity of this technology is now below 20,000 MW.

The primary obstacle hindering widespread adoption of this technology is cost; nonetheless, advancements have been as impressive as those seen in other leading solar technologies. In 2004, pilot plants incurred costs of approximately $0.45 per kWh, whereas third-generation systems, developed a few years later, cost between $0.17 and $0.20 per kWh. While not yet competitive with the efficient installation of gas or coal (see to Section 6), this cost is significantly lower than what most Nigerian households and businesses incur when relying primarily on household generators. Northern Nigeria and the Middle Belt are evidently situated atop a substantial energy reserve, which is rapidly becoming economically feasible. Considering that these regions present a more costly and complex electricity distribution from southern Nigeria, there is a compelling argument for a thorough investigation of the region's energy potential. The case for this is further bolstered by the extensive geographical distribution of solar thermal potential. In several instances, it ought to be feasible to envision low transmission lengths and comparatively rapid building in contrast to gas plants that depend on extensive pipes or protracted transmission networks.

A cautionary note: the expected competitiveness of solar thermal plants relies on medium to large-scale installations. The projected cost-efficiency improvements are predicted to reach up to 50 percent, scaling from modest pilot projects to cumulative installations of approximately 5000 MW. This does not diminish its total potential; however, it underscores the necessity for readiness to see the technology as a significant capital expenditure.

9.3 Alternative Renewable Energy Sources

Beyond the well-known solar photovoltaic technology, other renewable energy sources garner less consideration or focus. Hydropower, Nigeria's most substantial renewable energy source by current capacity, has served as the foundation of grid-based electricity generation for decades. Currently, analysts may identify notable hydropower sources and proposals, like the dam for the Mambilla plateau in eastern Nigeria; however, substantial investments and extended timelines have engendered scepticism regarding their advancement.

The most substantial change anticipated in the short to medium term regarding hydropower is the pressing necessity to revamp current hydro-generation systems. Current turbines are significantly outdated and generating only over 50 percent of their capacity. The most poorly comprehended source of renewable energy in Nigeria appears to be wind power. Until recently, Nigeria was perceived by both domestic and foreign policymakers as 'not a windy country,' a conclusion derived on a notably restricted dataset. There has been a notable scarcity of available data to either substantiate or refute this claim.

In 2005, Lahmeyer International evaluated wind velocities at 10 sites in Nigeria, determining average wind speeds of 4–5 meters per second at a height of 30 meters (suggesting 5–6 m/s at 80 meters). These modest speeds can indeed warrant installations in sites near the upper limit of this range, particularly in areas with the most stable conditions. The seeming disinterest in wind power appears to arise from the failure of these statistics to reflect the substantial resources available in certain 'windier' nations. The potential for wind energy in Nigeria is evidently less significant than the substantial potential projected for solar thermal energy.

Considering the enhanced price-competitiveness of wind power, the advancement of specialised applications at moderate wind speeds, and the relative simplicity of its modular deployment, wind power warrants increased research and pilot implementation in Nigeria. Comprehensive mapping would elucidate its potential for rural regions, especially when integrated with other power sources. Mapping in countries like the UK illustrates the degree of variance that emerges when generalised figures are replaced with unique local data. Although large-scale generation may be confined to select sites, the 'off-grid' potential of wind power in remote regions, especially the coastal Niger Delta, remains largely unexamined.

A substantial wind pilot project of 30MW is being established in Kano State, alongside a further pilot project in Katsina State. These may offer the inaugural locally accessible proof of the operational dynamics of grid-level wind power under local conditions for Nigerian policymakers and the public regarding the prospective role of wind energy. However, the implementation of smaller initiatives for off-grid rural communities should be prioritised. Frequently overlooked in extensive mapping initiatives, the creation of combinations could mitigate seasonal variations and other limitations. The most effective globally is the combination of wind power and diesel generating for periods of low wind speeds. The widespread presence of substantial 'community' diesel generators in the Niger Delta presents a clear opportunity to explore alternatives to the prevailing situation, where fuel supply issues frequently result in intermittent rather than dependable electricity provision from these generators. Solar and wind energy may be a viable combination for the same populations, as their seasonal strengths mitigate each other's limitations.

9.4 Investigating Uncharted Territory

The previous two decades of cautiously researching renewable energy in Nigeria underscore the importance of maintaining an open mindset towards advancements in new and enhanced technology. The fossil fuel industry in Nigeria is nearing its fiftieth anniversary, whereas renewable energy sources, aside from hydro, have just recently begun to get attention in the past decade.

Section 6 will examine the declining cost of renewable energy, as advancements in technology become increasingly accessible and efficient. However, it is not solely the expense of generating that is propelling new opportunities. This section will examine a significant development associated with renewable energy: advancements in energy efficiency across many equipment, including computers and air conditioners. The preceding sections have examined the possibility of specialised renewable energy uses and large-scale generation; nonetheless, the predominant energy consumption occurs within Nigeria's 'mass household market' with its 160 million inhabitants. Given the diverse requirements, a comprehensive analysis of Nigeria's domestic energy consumption is unfeasible; however, it is pertinent to underscore many critical issues that warrant exploration in the context of renewable energy.

The consumer-grade products discussed in Section 3 suggest potential trajectories for economical mass-market offerings. This trajectory will be shaped by some technological advancements already noted, as well as the essential and continuously evolving backdrop of generation and demand elaborated upon below.

10. ENERGY REQUIREMENTS AND ASPIRATIONS

There is less unanimity regarding household-level demand and energy requirements in Nigeria; however, it is generally acknowledged that the magnitude of the issue is significant. For an illustration of the extent of disparity, one need merely examine estimates of decreased demand for grid electricity. Assuming an endpoint of approximately 1KW consumption per capita, similar to that observed in most affluent nations, Nigeria's theoretical demand for electricity would be approximately 160,000MW, in stark contrast to the relatively minimal generation of under 5000MW currently produced.

The challenge of aligning demand with supply, prior to considering industrial requirements, seems daunting and distant from the 'stable electricity supply' assured by political figures for the forthcoming years. Lai Yahaya's future article addresses power generation concerns and strategies, whereas Figure 4.1 aims to depict the probable significant disparity between power demand and supply in Nigeria.

The estimates for electricity consumption and demand of 'off-grid' generators in Nigeria exhibit a remarkable variability. Official calculations estimate demand at 20,000 MW, however alternative assessments for a population over 160 million suggest far higher demand. Despite its robust industrial expansion, South Africa, with a population of 50 million, serves as a pertinent indicator, as its generation capacity of 40,000 MW barely satisfies demand. Figure 4.1 illustrates the persistent deficit if the 2007 demand was merely 40,000 MW, accompanied by a mere three percent yearly increase in power consumption. The disparity becomes far more pronounced when a starting point of 60,000 MW is regarded as a more precise estimate of demand.

Actual repressed demand is, undoubtedly, far more intricate than a singular headline calculation. A significant portion of Nigeria's population is unable to buy consumer items that would typically elevate energy usage to Western standards or higher. They would also likely struggle to bear the expense of the overall rise in energy usage. This has resulted in estimates of repressed energy demand ranging from 20,000MW to 80,000MW, with all analyses dependent on alarmingly little data.

Two inferences can be drawn at the household level from the limited data. The energy supply deficit for the bulk of the population will persist significantly for the next decade and beyond. The actual expense of electricity will continue to reflect the prices associated with commercial and residential generators, which start at $0.50 per kWh and increase from there. Reforms in the power industry will be crucial for economic growth stemming from increased grid energy output; nonetheless, power supply will be insufficient, leaving many regions essentially excluded or subjected to significant rationing.

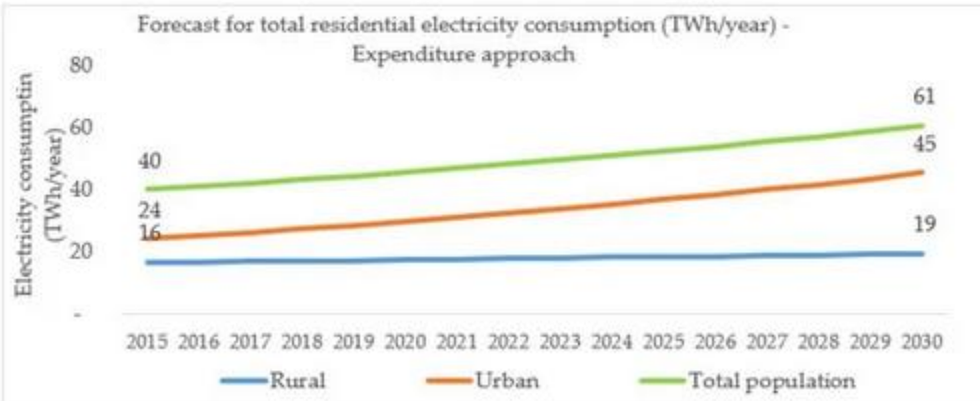

Figure 6. Projected electricity consumption in Nigeria Source: https://www.mdpi.com/2071-1050/10/5/1440

In the setting of power rationing and exploring other energy sources, Nigerian families would persist in prioritising a combination of affordability and accessibility. The issue of affordability will ultimately be influenced by circumstances largely outside the control of most users, chiefly the dependability of the power supply in their region.

10.1 Decentralised Renewable Energy (DRE)

The most efficient and pragmatic approach to enhance electricity access and diminish reliance on diesel generators is through decentralised renewable energy solutions. These encompass solar home systems (SHS), community-oriented mini-grids, and specialised installations for essential institutions such as educational facilities and healthcare centres. Decentralised renewable energy sources mitigate significant transmission losses and can be swiftly implemented in areas where grid expansion is sluggish or economically impractical. Ongoing initiatives spearheaded by the Rural Electrification Agency (REA), in collaboration with international development partners and financiers, are expanding mini-grids and advocating for energy-efficient productive-use appliances, thereby establishing reliable power access and fostering new avenues for local economic development (NCCC, 2023; ETP, 2023).

This report delineates three fundamental categories of energy consumers who may contemplate transitioning entirely or predominantly to solar power.

1. Households and enterprises outside the electrical grid. In rural locations lacking the promise of dependable grid electricity within around three years, consumers have a singular source of competition for renewable energy: petrol and diesel generators. Given cost structures of \$0.5/kWh or significantly more for generators, renewable energy can be instantly competitive despite substantial initial capital expenditures.
2. Individuals situated at the periphery of the grid. Although there is a scarcity of genuinely dependable statistics, it is evident that for a significant portion of the country, access to the grid entails an erratic supply of electricity, fluctuating between a few hours weekly to four hours daily. A significant portion of the population belongs to this group. Renewable energy remains competitive for this cohort due to the limited and inconsistent nature of grid supply.

There exists the potential for 'optional' high-energy-demand chores to be deferred to grid electricity, so considerably diminishing the size of the solar system required to meet other demands.

3. Those are 'just partially obscured.' In places like Lagos and Abuja, certain areas can anticipate 8–12 hours of electricity daily with relative consistency, in contrast to the remainder of the country. This group is expected to profit from an efficient inverter and battery backup system, which would utilise the lower cost of grid electricity while offering significantly superior and more economical alternatives to a generator during grid outages.

Table 1. Variations in Energy Efficiency for Domestic Products in Nigeria

Power consumption (watts)			
Product	2002	2012	Maximum efficiency (for a solar installation)
Lighting	600 (6 bulbs, 100W each)	120 (CFL bulbs)	80 (LED lighting]
Television	300	50 (flatscreen)	20 (LED flatscreen)
Fridge	500	300	150 or lower (energy-efficient versions)
Fans	150 (3@50W each)	150	120
Total	1550	620	370

10.2 Domestic Decisions, Energy Efficiency, and Renewable Resources.

Household decisions on consumer products to satisfy their demands will significantly impact energy demand in Nigeria and the significance of renewable energy. One of the primary obstacles to the broader adoption of solar electricity in nations such as Nigeria is the substantial initial capital expenditure. Evidence from specialist pilot applications indicates that selecting more efficient goods to fulfil requirements will significantly affect the overall system cost.

At the consumer level, savings achieved through energy efficiency or prioritising low-energy needs influence every aspect of a solar power system: fewer panels are necessary, a smaller inverter suffices, and the quantity of batteries is significantly diminished. Consequently, it is evident that advancements in energy efficiency over the past decade have significantly enhanced the likelihood of modest solar installations fulfilling household requirements. Table 4.12 delineates modifications that are comparatively attainable in Nigerian markets.

Moderate-income households utilising appliances depicted in Table 4.1 have experienced a reduction in energy requirements by over two-thirds when employing contemporary iterations of commonly used consumer products. The increases are inconsistent; nonetheless, in many instances, advancements in areas such as computers and lighting have prompted forecasts of significant progress occurring nearly as rapidly as the standard in computing power.

The author derives energy use figures from 'average' commercially accessible products in Nigeria. 3 Regarding the advancements in the efficiency of computer products, many of which are currently propelling the revolution in smartphones and mobile computing, refer to http://www.extremetech.com/
computing/95913-koomeys-law-replacing-moores-focus-on-efficiency-with-power.

The concluding column of Table 4.1 denotes the reductions achievable with supplementary investment, despite the persistent challenges in Nigeria where options remain severely constrained. The aforementioned choices do not address the intermittent demand from high-consumption equipment like irons, kettles, and water heaters, although they significantly underscore the potential reduction in energy requirements to satisfy essential daily needs.

The table also emphasises two additional concerns: the necessity for consumers to understand their energy alternatives and the significance of cost-effective 'high-efficiency' technologies. In the absence of more efficient products tailored to local requirements, these benefits may remain theoretical for numerous households and small enterprises. The accessibility of more efficient products is essential for consumers contemplating the possibility of using solar energy.

10.3 Consumer Education, Choices, and Supply Chains

A distinct opportunity for renewable energy exists at the household level in several regions of Nigeria. Significant declines in solar power prices and energy demands create a formidable synergy to rival generators. However, these are merely two essential components of the more intricate puzzle of consumer decisions.

Essentially, substantial progress towards renewable alternatives will not occur until there are evident and accessible solutions that address household need. Disregarding initial expenditures, the market features a limited number of dealers for domestic solar systems, and their reliability is markedly inconsistent. Although the availability of energy-efficient items has improved somewhat, consumer and distributor awareness regarding the energy worth of these products remains low or frequently absent.

A straightforward 'catch-22' predicament seems to be in operation. The capital expenses associated with solar systems are hindering the advancement of supply chains for solar and efficient products, limiting consumer options for inexpensive combinations that meet their requirements. However, enhanced supply chains, consumer education, and access to the newest cost-effective innovations will provide a further reduction in costs, potentially stimulating substantial demand. Policymakers, suppliers, funders, and investors evidently share a mutual interest in resolving this 'catch-22' predicament. Their duty is exacerbated by the current circumstances. The subsequent section of this article delineates a severely impaired market for renewable energy goods. However, the fundamental trajectory becomes distinctly evident—technology has evolved and been substantially validated. The remaining tasks include market research, further adaption, and product combination to align with the requirements of a highly diversified community.

10.4 Is the market fractured?

Given the advancements in niche solar uses and the swift improvement in energy efficiency and cost reduction, one may anticipate a rapid expansion of Nigeria's renewable energy business. The Nigerian solar business is characterised by sporadic instances of success overshadowed by several government-sponsored projects that exhibit an exceptionally high failure rate. Rather than a vigorous market gaining assurance, there exists an emerging sector impeded by a reputation that has significantly deteriorated over the last five years, especially in southern Nigeria.

Moreover, there exists a significant hesitance among individual users to invest in renewable energy systems (or even inverter-battery backup systems) due to the substantial initial expenditure. This interacts with a deficiency of accessible evidence for average consumers regarding the likelihood of their investment's success. Identifying trustworthy vendors and installers for solar equipment, together with substantiation of successful models, is challenging and labour-intensive. The situation is exacerbated by the frequent lack of dependable warranties or service providers capable of delivering both high-quality equipment and maintenance. This section examines the primary causes of a decline in market confidence and potential treatments.

10.5 Patronage Contracting

The substantial capital investment required for solar projects has rendered them appealing to government entities that favour large-scale initiatives and invest with minimal understanding of necessary objectives, contractors, and technical fundamentals. This seeming disregard and absence of accountability appear to be only an extension of the patronage contracting issue, where the interests of administrators and contractors are focused on maximising profit.

Project completion and short-term sustainability seem to be variable criteria, where the extent of permissible actions significantly impacts implementation more than adherence to best practices. Regrettably, this issue is not exclusive to solar energy. This phenomenon in development contracting occurs when numerous key stakeholders prioritise patronage and dubious contractual prospects over the ultimate outcome.

Examples that are recognised include:

- The Niger Delta Development Commission has commissioned numerous major solar water projects, each above $300,000, since 2006. Concise surveys indicate that the overwhelming majority of this initial phase of initiatives were either never finalised or failed shortly after implementation.
- Projects pertaining to the Millennium Development Goals. This presidential agency either contracts development projects or collaborates with states. Reviewers have raised concerns that most projects seem to fail shortly after initiation, with inadequate implementation and maintenance being the predominant issues. These deficiencies are not exclusive to large federal government agencies but are also evident in various extensive state initiatives in Nigeria. Nasarawa State commissioned 147 solar water projects in 2004, aiming to offer one for each ward within the local governments of the state, according to an interview with an unnamed consultant due to the ongoing review status. A evaluation conducted by Iceberg Consulting, commissioned by the state government, revealed that 83 percent had not succeeded. The causes of failure are akin to those that the reader will encounter repeatedly throughout this report:
- Ineffective technical system design and installation
- Improper acquisition of borehole and solar array installation
- minimal or no training provided to the end users within the community
- insufficient upkeep.

The prevalence of substandard work executed via patronage contracting persists, accompanied by few reactions to evident issues. Similar to other development initiatives in Nigeria, there is a lack of effective oversight over service delivery and accountability for sponsors of numerous unsuccessful projects.

The impairment of the impression of renewable energy, both in governmental circles and among the populace, is considerable. An escalating number of towns have had failures in solar projects, likely surpassing those with favourable experiences where their systems continue to operate effectively after several years.

10.6 Challenges Associated with Solar Street Lighting

Solar street lighting initiatives have adversely impacted the views of renewable energy in Nigeria more than any other deficiency within the nascent industry. Since around 2003, they gained popularity among state governments as a rapid solution for inadequate lighting in urban areas resulting from unreliable grid electricity. Nevertheless, the installed systems generally employed inexpensive and inadequately integrated components, miscalculated battery demand, and experienced substandard installation and insufficient maintenance.

Many designs observed in Nigeria use batteries placed within a metal enclosure on the streetlight pole. In tropical regions, this can be a detrimental decision as battery longevity is typically significantly compromised by elevated temperatures. Numerous devices may have failed due to their batteries being overheated by the solar energy they were designed to store. Most state-installed systems are claimed to have malfunctioned within approximately six months. In Rivers State and Bayelsa, the majority of solar systems installed circa 2006 were dismantled and substituted with conventional lighting due to their failure within 12 to 18 months. In several states, malfunctioning solar street lights serve as a mute testament to improper solar installation practices.

Implementing effective solar street lights is tough yet feasible. The required illumination is at the higher limit of solar power capabilities without incurring prohibitive expenses, however this has significantly improved with the introduction of LED lighting. Two exceptional instances illustrating this in Nigeria are the lighting system at FERMA in Abuja and a supplementary system implemented by Iceberg Consulting in 2003 in Nasarawa State, which continues to operate eight years later.

10.7 Inconsistent quality across installers and vendors

The renewable energy marketplace appears weak in comparison to other regions with considerable grid deficiencies, such as Kenya. The extensive generator market developed over decades in Nigeria, catering to needs from under 1kVA to major hotels, underscores the substantial growth necessary for renewable energy to play a significant role in the country's overall energy mix.

Until recently, the limited renewable and solar vendors in major cities appeared to depend predominantly on contracts from government entities or oil firms for installations, which they frequently lack the qualifications to execute proficiently. Vendors frequently appear to be a blend of the inexperienced, possessing commendable yet occasionally naïve goals, or more cynical entities that exhibit minimal regard for their products, provided they can only pass an initial inspection and formal commissioning. High-quality installers and vendors exist, but they are infrequent and typically difficult to locate for individuals lacking established networks.

The feeble position is exacerbated by the hesitance of private individuals to invest the necessary capital for a modest home system or comparable alternatives. Two solar dealers interviewed by the author acknowledged that they had not installed solar systems in their residences due to the cost, despite residing in areas where grid electricity was frequently accessible for just 2–4 hours daily.

The difficulty for the public and prospective sponsors of renewable projects in locating competent, seasoned practitioners is significant. The cautious emergence of renewable energy in Nigeria has rendered individuals with 5–10 years of experience in the sector both scarce and somewhat isolated. Throughout the preparation of this paper, the author encountered well-meaning persons with the resources to invest in small solar installations, yet lacking knowledge on how to identify a good company to execute the operation.

In Nigeria, there exist just a few associations of solar or renewable energy practitioners, mostly affiliated with other organisations. The Ministry for the Environment's renewable energy program maintains a database of stakeholders; nonetheless, this does not mitigate the relative isolation of professionals in a diminutive business inside a vast country.

10.8 Instructional Insights and Market Remediation

The harm inflicted on the market by the proliferation of unsuccessful sponsored solar initiatives over the past decade, along with several dubious minor items, cannot be rectified swiftly or effortlessly. The significant harm to views indicates a clear focus area: prominently showcased 'best practice' projects designed to exemplify cutting-edge technology and alter public opinions.

The government plays a crucial role by providing venues and locations for installations that will be regularly observed. The government maintains a proficient central hub for its renewable energy initiatives at the Ministry of the Environment. It is realistic to anticipate that projects focused on enduring quality and attitude transformation could originate from this location.

Addressing market issues necessitates a meticulous integration of market intelligence, targeted consumer education, financial support for emerging industries, enhanced vendor visibility, and regulatory measures to foster market confidence. Such endeavours to establish 'an industry' might readily misfire or yield unforeseen repercussions. Consequently, it is imperative that these measures are meticulously formulated in conjunction with established practitioners.

The subsequent section of this article examines a crucial aspect of market development—financial requirements for a sector characterised by significant upfront capital expenditure. Addressing these concerns collectively as a cohesive approach will facilitate a definitive pathway towards a robust renewable energy market.

11. FUNDING RENEWABLE ENERGY INITIATIVES IN NIGERIA.

The funding of renewable energy initiatives is regarded by both professionals and analysts as the primary obstacle to the increased adoption of renewable energy. Even individuals closely associated with the tiny industry have refrained from implementing systems due to the substantial capital expenditure and the protracted 'payback' period in a challenging market. This part will address the emerging difficulties related to capital expenses and the resulting financing requirements for households.

11.1 Adjusting Capital Expenditures

The substantial capital expenditures of solar products have been identified as a significant obstacle to the adoption of this technology, regardless of consumers' economic levels. The disparity is considerable in both residential and commercial systems within a predominantly cash-based economy. This is applicable at all tiers within the market. A homeowner may be evaluating a solar lamp priced at N3000, which requires no energy inputs, against a kerosene lantern costing N300, which necessitates ongoing fuel expenses. Another instance is the decision between investing N40,000 in a generator or N200,000 in a small solar/inverter system. The problem of securing initial finance for solar systems is significant in all instances.

For consumers to make a significant commitment to renewable sources, the benefits must be unequivocally evident. In many instances, this indicates that aligning a consumer's energy requirements with the most efficient renewable alternatives is essential for securing both acceptance and substantial benefits.

11.2 The Mitigation of Core Costs in Solar Photovoltaics

Currently, with a little market and very minimal revenue, it appears improbable that the reductions in the cost of solar PV electricity have entirely permeated Nigeria. It appears improbable that these expenses have been entirely incorporated into the calculations conducted by suppliers and installers of solar systems.

Nonetheless, the decline in prices has intensified during the last four years. Although there is a degree of variability in the optimism reflected in Figures 7 and 8, the comparison of photovoltaic (PV) energy to alternative sources conveys a consistent message: the significant advancements in solar technology suggest that the issue is not whether, but when solar power will surpass existing fuels in competitiveness.

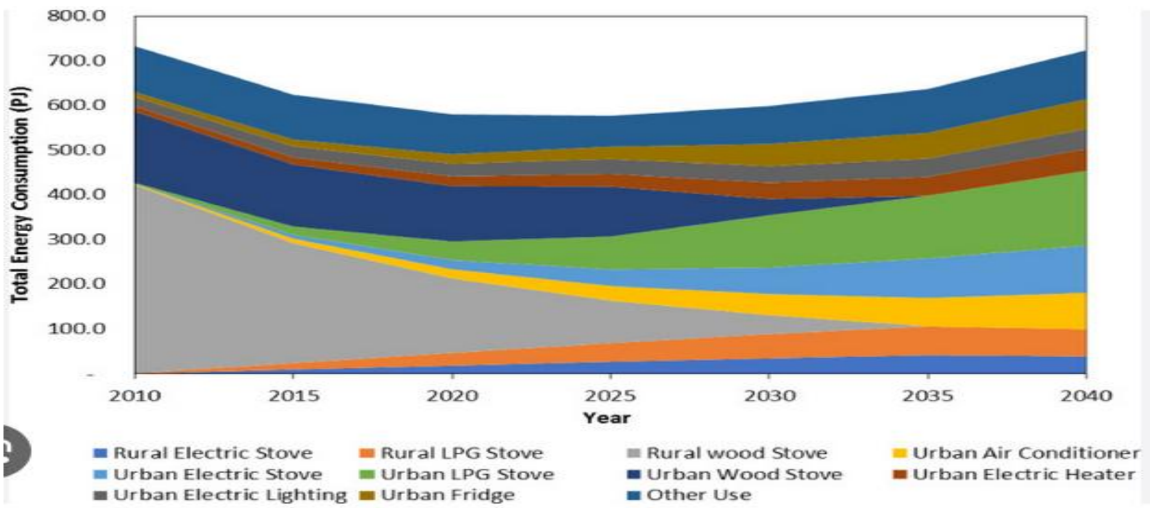

Figure 7. Forecasted cost of solar photovoltaic versus conventional, 2005–2035 Source: https://www.pv-magazine.com/2025/06/18/nigeria-expected-to-hit-only-1-5-gw-of-solar-by-2035/

Figures 7 and 8 both underscore two prevalent themes. The initial factor is the persistent decline in the fundamental costs of renewable energy. The effect of this at the home level may be exaggerated (see to Section 6.3), however the magnitude of the decline in costs remains favourable at both macro and micro levels. It has ramifications for business planning, even in the short term, emphasising the necessity for installers to access superior current products and for their clients to be informed about options that incorporate the latest advancements.

Figure 8 exemplifies several estimates of electricity price trends; nonetheless, it is crucial to recognise that it consolidates 'average' costs rather than emphasising actual local situations. The elevated expenses associated with generation infrastructure projects in Nigeria suggest that conventional power costs are considerably higher, with a substantial dependence on gas for generation. Secondly, both figures juxtapose renewable energy with current grid power alternatives. Given the limited access to grid electricity in Nigeria, dependable grid power is not a feasible choice for the majority of Nigerians. Section 6.4 seeks to contextualise the contrast between renewable electricity and its primary realistic competitors among generators.

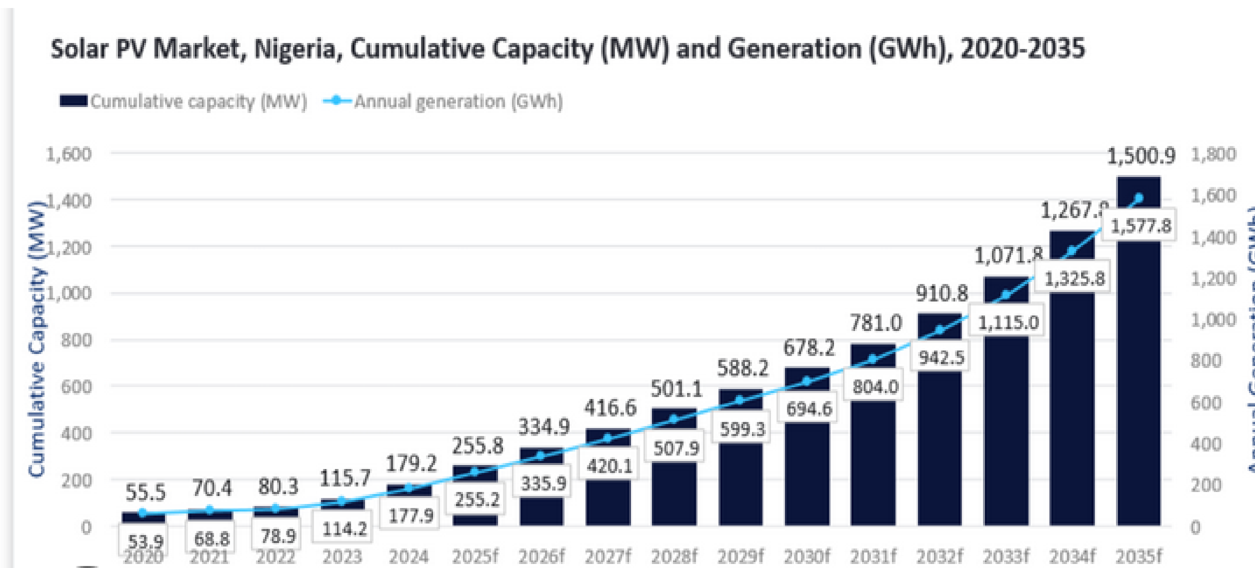

Figure 8. Anticipated expenses of various energy sources, 2010–2035
Source: https://www.sciencedirect.com/science/article/abs/pii/S2666278721000428.

11.3 Installation Expenses

In smaller projects, both in Europe and Africa, the decline in solar panel prices and diminished energy requirements have underscored a fundamental challenge. The installation cost of a system, rather than the theoretical efficiency of a panel, is the primary factor influencing cost and value. This renders labour costs and industry efficiency increasingly pertinent in assessing potential advantages for customers.

In Nigeria, the diminutive scale of the renewable sector seems poised to maintain elevated installation costs compared to other nations, at least in the short future. This also highlights another essential objective. Given that labour costs in Nigeria are lower than in many nations used for installation comparisons, it is essential to cultivate professionals capable of delivering competent and cost-effective services. The growing body of analysis emphasises that the majority of jobs related to renewable energy are to installation and maintenance, rather than the increasingly mechanised manufacturing sector.

Alongside cost and energy efficiency, quality is equally crucial for dependable components.

Nigeria presents numerous dangers that might significantly impair equipment, rendering renewable energy capital investments considerably more costly if challenging repairs or replacements become necessary. Investing in supplementary protection against hazards such as lightning, accidental damage, or misuse has demonstrated significant benefit in experimental projects, and this approach is likely applicable to most consumer scenarios.

Ultimately, these expenses underscore the advantages of certain smaller 'product' solutions where they are suitable. High-quality solar lanterns or compact DC lighting systems do not necessitate specialised installation expertise and, when equipped with LED lights, exhibit remarkable durability against damage and misuse. Consequently, compact modular programs evidently possess a significant edge in capitalising on recent advancements.

11.4 The Competition: Generators and Kerosene

When evaluating the expenses associated with renewable energy, a significant consideration sometimes overlooked is the exorbitant amount that the majority of Nigerian consumers presently incur for lights and power. Surveys indicate that 50 percent of the population lacks access to grid electricity, while many others have limited access for only a few hours weekly; thus, the primary energy sources for a substantial segment of the population are derived from alternative means.

Acquiring comprehensive expenditure and cost assessments is difficult. The majority of customers limit their utilisation of generators, lanterns, and alternatives, while there is significant heterogeneity in the efficiency of the devices employed. Moreover, these calculations fail to consider the expenses associated with substandard fuel (which diminishes generator lifespan), fuel procurement, and erratic price fluctuations and shortages. A more thorough review of these expenses for the majority of consumers is likely to persuade them that a well-engineered solar system will reduce the operational costs of a generator or the daily expenditure on kerosene for lanterns.

Bermuda and other island nations exemplify the indicative costs for household consumers in isolated places dependent on diesel. This region is initiating a significant initiative for energy efficiency and enhanced utilisation of solar power, partially in response to grid electricity pricing of \$0.45/kWh. Individuals involved in rural initiatives may also reference detailed information from an extensive evaluation in Namibia, which monitored decreasing payback periods and performance metrics aligned with the experiences of NDWC in the Niger Delta. In both instances, data predating 2010 demonstrated that the duration required for larger capital expenditure in solar systems to yield net savings was less than three years and decreasing. Post this juncture, savings would signify a substantial benefit for communities and investors.

11.5 Feed-in Tariffs

Representatives from both NERC10 and the federal government of Nigeria have expressed their willingness, albeit without specifics, to establishing a renewable energy feed-in tariff aimed at fostering industry growth. In numerous nations with advanced renewable energy infrastructure, "feed-in tariffs" encompass compensation that residences and small enterprises can obtain for surplus power they generate and contribute to the electricity grid. Nonetheless, the majority of analysts and stakeholders in the power sector have informally deemed this notion unworkable in Nigeria due to the precarious and disordered condition of the current system. This is likely accurate for small installations or families, but may not be readily dismissed for larger enterprises capable of sustaining substantial renewable energy.

If the federal government recognises the robust economic rationale for the development of renewable energy in the longer term, particularly in northern Nigeria, then the implementation of feed-in tariffs to incentivise sector growth should be meticulously evaluated. In Europe, where numerous technologies possess fewer inherent advantages, the feed-in benefits are considerable. The United Kingdom is currently decreasing its green feed-in tariff to a substantial 21 pence (52 Naira) per kWh, down from over 40 pence (104 Naira).

This rate may appear excessive in Nigeria, where analysts anticipate the gross tariff (prior to any temporary alleviation) to increase from the current 10 Naira to between 20 and 30 Naira per kWh. Conventional estimates of generator costs, approximately 70–80N ($0.45–0.50), underscore the necessity of scrutinising the comprehensive context of cost-benefit evaluations. It is important to note that certain issues associated with renewable energy may be perceived as advantages within the framework of Nigeria's challenging power circumstances (Table 6.1).

Additional hazards exist within the framework of a feed-in tariff for Nigeria. Fuel subsidies have demonstrated to be detrimental avenues for contract exploitation and fraud. Any feed-in tariff must function with exceptional transparency within a demanding market environment. There is a compelling argument for using feed-in tariffs to accelerate the large-scale development of renewable energy in northern Nigeria. This could potentially facilitate a swift enhancement of power accessibility. Nonetheless, the advantages would be permanent only if lessons regarding power management, contracting, and oversight are thoroughly assimilated. The establishment of a more credible NERC is an essential initial step; nonetheless, the pivotal component is expected to be substantial progress on comprehensive power-sector reforms.

11.6 Capital Accessibility

Access to credit at reasonable interest rates is essential for facilitating investment in renewable energy, whether at the home level or in large-scale generation. The predominant portion of expenses related to any renewable energy producing system is incurred upfront. In battery systems, substantial expenditures arise after five years when battery replacement is necessary, but other components, such as panels, are anticipated to endure for 15 to 20 years or longer. The durability of renewable energy systems is essential for calculating electricity prices and is key to rationalising the initial higher installation expenses.

Sufficient capital is essential for overcoming the 'payback period' in financing renewable projects. This refers to the duration necessary for savings from 'free' renewable electricity to surpass the expenses associated with grid or generator power, which entails consistent billing or fuel requirements. Nonetheless, if the primary source of capital is loan financing and interest rates are prohibitively high, the expenses associated with the loan constitute a significant component of the total cost. In Nigeria, the prevailing interest rates commence at approximately 25 percent annually, accompanied by stringent collateral requirements, presenting a significant challenge. The necessity for accessible loans has been acknowledged for an extended period in Nigeria. The Bank of Industry is progressively committed to provide loans at a low interest rate of 7 percent per annum or below. Nonetheless, this is inadequately actualised at present, hindered by obstacles in financing availability and adoption.

Alongside low-interest capital, numerous other critical measures must be implemented concurrently. Renewable energy providers must generate significantly more comprehensive cost analyses and pragmatic payback timelines for the entire spectrum of installations, from generation facilities to residential systems. For domestic or independent systems, the complexity is minimal; yet, publicly accessible data remains limited. There is an urgent need for additional information regarding consumers' willingness and capacity to pay bills, enabling both prospective investors and customers of renewable systems to clearly understand the anticipated costs and advantages. Loans will be employed just when enhanced access to cash is accompanied by reliable information and options.

The Views of the Nigerian federal government is that considering the substantial capital expenditures and extended timelines necessary for the development of commercial power generation via solar, wind, nuclear, and biomass, the Federal Government will concentrate its development initiatives on hydro, coal, and natural gas. The potential of natural gas will be recognised, and incentives will be offered to investors to fully harness this resource.

This article aims to investigate the current state of renewable energy in Nigeria, analyse the factors contributing to the sector's underdevelopment relative to other nations, and evaluate increasing evidence of the possibility for renewable energy to assume a significant role. Certain emerging recommendations are very straightforward to encapsulate:

- Pilot programs have illustrated the potential of renewable energy in Nigeria, along with certain persistent problems.
- Ongoing advancements in technology and fluctuations in costs have generated significant potential for interventions of both local and large scales.
- Strategically developed initiatives in markets, education, and finance are now substantiated investments for renewable energy to realise its promise in Nigeria.

Table 2: Challenges and Responses Regarding the Costs of Renewable Energy in Nigeria

Challenge	Response
High initial capital cost of installing renewable energy—whether wind, solar PV, hydro, or solar thermal.	The upfront capital investment cost has some advantages in Nigeria—there are no questions about the ongoing financial and stability issues of fuel and pipelines.
Solar and wind power are clearly better suited to specific parts of Nigeria for the most competitive solutions.	The areas with overwhelming solar potential (northern Nigeria) are very poorly served at present, and seem likely to face very high transmission costs from growing power generation areas in the Niger Delta.
Renewable energy installations have tended to be relatively small compared to conventional grid generation.	Smaller installations near to target communities should mean faster deployment and much lower transmission losses than distant gas-powered options.
Grid-level renewable energy is not an 'always on' generation solution. Both solar and wind require complementary generation.	Nigeria's power shortages are so acute that this may be an acceptable shortcoming initially. As the grid improves, Nigeria has a wide range of sources that should complement renewable sources well.

The feed-in tariffs used as a tool in other countries could prove expensive at a time when Nigeria has difficulties funding infrastructure.	If structured correctly, a green feed-in tariff could prove attractive to agencies such as the World Bank, with a good potential match in the longer term between affordable interest rates and economically sensible green outcomes. The existing cost of power to the private consumer is extremely high, making even the more expensive renewable options competitive.

Regrettably, the actionable measures necessary for an improved energy future in Nigeria, characterised by a robust renewable industry, are considerably more complex to condense into a succinct list of bullet points. While the goals for certain critical phases can be articulated clearly, the process will likely entail the integration of a multifaceted array of stakeholders, funding, education, and technology. Certain challenges may be addressed alone; however, numerous others necessitate effective coordination and teamwork. The notable failures of questionable solar initiatives, which entail substantial government expenditure, illustrate that renewable energy necessitates essential proficiency in planning and development for success.

In addition to proposing a modification in the government's main policy attitude, it indicates the relatively preliminary measures that could be achievable with minimal governmental investment, potentially yielding significant benefits for Nigerian households and fostering wider acceptance in this rapidly evolving sector. A successful foundation at this level is likely essential for garnering broader support for significant advancements, including informed investment decisions in large-scale solar power generation.

11.7 A Necessity for a Transformation in Energy Policy

Emerging research unequivocally indicates that Nigeria possesses a more substantial array of renewable energy resources than previously acknowledged. Moreover, international research indicates that these resources are rapidly becoming competitive with current electricity sources. The current exorbitant energy costs in Nigeria render renewable energy competitive or superior in numerous specific scenarios, particularly in providing targeted support to individuals with the lowest incomes. Energy policy must recognise that the rejection of renewable energy as a viable short- to medium-term option in the official Energy Road Map was a critical error. This indicates that renewable energy cannot be hastily prioritised; rather, it necessitates methodical policy, research, and financial backing for the advancement of the renewable energy sector. A proposal was formulated in 2005 with the Renewable Energy Masterplan, which ultimately was not implemented. Rapidly formulating and executing a revised strategy for strategic investments in renewable energy, integrating insights from the preceding decade, is an essential initial step.

11.8 Comprehending and Instructing the Market

While government policy is significant, it is essential for government and other stakeholders to recognise that many optimal energy solutions will emerge in the marketplace, where the government's role may primarily be to mitigate complexities. Renewable energy is already competitive with current sources for numerous requirements, and the primary challenge is to synchronise demands, solutions, and accessible money. Progress will be constrained unless both energy consumers and providers possess a significantly enhanced comprehension of their respective demands and feasible energy solutions.

To facilitate market-driven demand, a prominent array of experimental initiatives and educational programs appears essential prior to broad adoption by understandably hesitant customers. Research is required to analyse household requirements, earnings, and desires. The varied circumstances of rural and urban households, characterised by significant disparities in income and living expenses, necessitate a corresponding array of renewable energy solutions that can be more readily tailored to specific conditions. This data enables renewable energy suppliers and vendors to offer products and systems that align with actual needs.

11.9 Fostering developers, educators, and collaborators

This is considerably more challenging in practice, particularly within a political environment that prioritises local content in industry. Nonetheless, as indicated in the Renewable Energy Masterplan of 2005, there is a necessity for strategic investment in both research and business development to expand and consolidate potential for an emerging industry.

A foundation of local knowledge is essential for the development of practical projects. This could be effectively complemented by international experience, which may assist Nigerian firms and government in keeping pace with the swift advancements in technology abroad.

11.10 Aligning capital expansion with developing capacity

The government's financing in Nigeria's electricity industry has a problematic past, and rampant corruption in the fuel business has tarnished the reputation of subsidies. As emphasised in Section 6, there is an urgent requirement for financing for both consumer and grid-level products. Research conducted with solar industry professionals and consumers indicates that there is no definitive solution for finance; however, the following points are noteworthy:

- Additional capital should not be evaluated in isolation; it will be significantly more successful when assessed alongside other initiatives.
- Business mentoring and strategic guidance appear to be critically required for small and medium-sized enterprises. This should be explored diligently. partnership to augment the capital accessible to enterprises.
- Capital support for installment payments becomes feasible in certain consumer sectors, especially for civil servants and individuals with stable incomes.
- Subsidies for consumer goods should not be categorically rejected. Emerging technologies seem to provide enhanced mechanisms for accountability and assurance that benefits are directed to their intended recipients.
- The government's primary function may be to finance a strategy that ensures accessible capital increases in accordance with the renewable industry's attainment of verifiable milestones. Investors in renewable energy must be assured that accessible financing will persist as they progress.

11.11 Incentives for Efficiency and Demand Mitigation

The strategic plan for Nigeria's power sector, along with the prevailing industrial mindset, is currently focused on significantly augmenting supply. It has been clearly established that the most cost-effective method to satisfy total power requirements is to diminish demand whenever feasible, without detracting from customer experience. In essence, decreasing the consumption of one million users by 10 percent (equivalent to around 500 watts of peak demand) can be more expedient and significantly more cost-effective than constructing an additional 500MW thermal power plant. In the realm of renewable energy, it is prudent to explore ostensibly extreme alternatives—regulatory incentives for small-scale systems or village-level initiatives that operate fully off-grid or maintain little connectivity.

Although formally detached from the conventional electricity industry, those opting for this alternative are making a little yet impactful contribution to diminishing total demand, so enhancing the stability of supply for those connected to the grid. Offering further incentives to a nascent sector may expedite the development of viable off-grid installations, which continue to encounter elevated costs related with emerging technologies and are frequently contemplated for somewhat isolated rural regions with inherent obstacles. Enhancing the efficiency of essential appliances significantly lowers the capital expenditure of a solar system.

11.12 Supply Chains, Customs, and Regulations

The diminutive scale of Nigeria's renewable economy poses considerable challenges for installers, particularly when exacerbated by the widespread availability of inferior items, notably batteries and inverters. Importation has seen theoretical advancements with a zero tariff; nonetheless, numerous and costly hurdles persist for novice importers in practice. The recent experience of a 'Light Up Africa' dealer is enlightening. Customs officers initially classified integrated solar lights as lanterns, imposing a 35 percent duty, and subsequently applied additional charges that escalated the total importation cost to 100 percent of the original price.

This circumstance appears to be ordinary but is partially attributable to entrepreneurs with insufficient business acumen who may also lack the networks to navigate such challenges effectively. For low-income Nigerians to benefit from renewable energy technology, it is essential that pertinent government entities acknowledge this sector as one deserving of support, necessitating a favourable interpretation of rules at all levels.

The government could contemplate a comprehensive interpretation of solar and energy-efficient products to incentivise the late entry of complementary products into the mass market in Nigeria. Appropriate possibilities appear to include all deep-cycle batteries, inverters, energy-efficient refrigerators, low-energy air conditioners, low-energy light bulbs (particularly LEDs), and more low-energy devices as they become available.

Given the escalating issue of inferior components, it may be prudent to propose that Nigeria establish guidelines for imported solar products. Currently, both customs and other governmental agencies lack the capability to credibly test or certify products. This area should undergo meticulously planned development, with regulation introduced only when the government can clearly execute policies both equitably and efficiently, without imposing excessive costs on legal suppliers. Consequently, the involvement of non-governmental entities in cultivating respectable brands and reputations becomes increasingly vital.

State governments, whose rural regions and low-income citizens could gain from suitable low-energy products, should contemplate significantly cutting operational expenses for renewable energy enterprises. The numerous municipal fees and often unwarranted harassment of small businesses by different local government entities constitute a substantial obstacle for small and medium-sized enterprises in the renewable energy sector. Mitigating these obstacles would provide a favourable impetus for swift growth.

Ultimately, the government could assume a crucial regulatory function in anticipation of future developments. Building standards in Nigeria are inadequately enforced, however appear to be progressing in certain regions. Nigeria ought to establish building standards that, while avoiding excessive costs, encourage the integration of low-energy concepts throughout all phases of development. These laws may be incrementally enhanced as diverse solutions become increasingly viable and accessible at reasonable costs.

11.13 Government as an Advocate for Renewable Energy

A primary objective of the electricity sector reforms is to eliminate government involvement in operations and ownership, relegating its role predominantly to regulation. This policy is based on the state's catastrophic management of the industry and investment during the last forty years. Consequently, advocating for government engagement in the renewable energy sector should be approached with prudence.

The government can clearly target certain sectors to rectify financial deficiencies. This should ideally involve close engagement with highly trained partners utilising models that incorporate the extensive lessons learnt from worldwide experience over the past two decades. The specified locations encompass:

- Elevated capital expenditure for small residential and commercial installations, coupled with challenges in securing cheap financing.
- Financial assistance for emerging technologies in which private investors may exhibit insufficient experience and confidence, with solar thermal serving as a quintessential example.
- Capital expenditures for established renewable technologies, including solar photovoltaic and wind energy, in suitable places.

The federal government currently funds numerous solar PV systems via the Energy Commission of Nigeria, NDDC, and other entities. Nonetheless, as detailed in Section 5, there is an imperative necessity to evaluate the quality and medium-term results of these pilot programs. Government-sponsored pilots remain valuable for establishing new technologies; nevertheless, they must have a much reduced failure rate compared to the current standard.

Considering the magnitude of federal and state governments, together with their services, inside the Nigerian economy, there are clear advantages for state entities to progressively implement renewable and low-energy technology. In certain regions, there have been tentative measures taken, such as the implementation of low-energy lighting policies; nonetheless, significantly more action is required.

Given that state services frequently experience persistent funding deficits for power, largely reliant on generators like other entities, there are clear advantages in transitioning more services to renewable energy whenever possible. Considering recent developments, it is imperative to ensure that any conversion is both economically viable and executed by credible firms capable of proposing solutions tailored to specific local requirements.

Two preliminary steps exist:

a) Initiate partnerships that develop best practices for many critical sectors (e.g. educational institutions, healthcare facilities, governmental edifices) of diverse magnitudes in prominent places.
b) Expedited research that delineates suitable goals and immediate gains for renewable energy and energy-efficient alternatives, accompanied by essential guiding principles for subsequent actions.

The government has a significant role in both endorsing and actively engaging in public education regarding energy. For the potential benefits of renewable energy and enhanced efficiency to be fully exploited, communities, businesses, and the public must be much better educated about the fundamentals of energy consumption. The secondary school education project launched by the Lagos State Government, incorporating an online component and emphasising energy saving, exemplifies a commendable effort that could have numerous beneficial ripple effects. Incorporating teaching on energy matters, especially renewable energy, into school curricula and significantly increasing the availability of written resources appears to be a wholly suitable responsibility for the government.

Educational programs should extend beyond schools to encompass a diverse array of adult audiences. Innovative measures, like collaborations with churches and mosques to showcase sustainable energy alternatives, should be contemplated alongside other possible promotional avenues. The government must evaluate the role of renewable energy in the tertiary sector, where substantial investment in teaching and research is essential. Practitioners have accurately recognised the pressing demand for proficient technicians, a necessity that will intensify if the sector is fostered to evolve. Nonetheless, with the argument for expansion, there exists a valid rationale for investing in each of the following:

- Technical training for technicians aimed at individuals with prior electrical experience (generator suppliers and repairers).
- Professional development for solar and renewable engineers will necessitate international scholarships until local capability is established.
- Facilitating reputable institutes to investigate renewable energy, emphasising the timely implementation of optimal technology for Nigeria.
- Diligent cultivation of local manufacturing, maintenance, and support facilities that should progress alongside the increasing familiarity with emerging technology.

12. CONCLUSION AND RECOMMENDATIONS

Formulate cohesive strategies for renewable energy planning and investment.
The federal government must enhance its current activities by formulating a cohesive renewable energy strategy and implementing a substantial escalation in funding for research, market development, and regulation of renewable energy.

Facilitate incentives for the adoption of renewable energy.
The government should contemplate incentives, potentially via a feed-in tariff, for at least one significant trial project of solar thermal power generating in northern Nigeria.

Guarantee enough and cost-effective capital funding.

Systematic expansion of low-interest capital finance for renewable energy is essential, with capital availability increasing in accordance with industry growth.

Enhance public comprehension of renewable energy.
Stakeholders in the renewable sector and government must invest substantially in public education to enhance consumer and policy decisions and to dispel prevailing biases against the industry.

Foster cooperation between renewable energy developers and policymakers.
Policymakers and renewable energy developers must collaborate closely to establish optimal service practices in rural regions, notably with education, healthcare facilities, and water supply.

Instruct on energy use and efficiency.
Energy utilisation, namely energy efficiency and renewable energy, must be integral to the educational framework as promptly as possible, aiming to transform public behaviour and enhance engagement in the burgeoning renewable energy sector.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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