IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 5 Ser. 2 (Sept - Oct 2025), PP 01-12
www.iosrjournals.org

Evaluating The Impacts Of Hybrid PVS Adopted By Commercial Buildings In Nigeria

Author

Abstract
Nigeria's commercial sector faces persistent electricity shortages, high operational costs, and environmental challenges due to heavy reliance on grid supply supplemented with diesel generators. This study evaluates the impacts of hybrid photovoltaic (PV) systems adopted by commercial buildings in Nigeria, focusing on economic performance, environmental sustainability, and energy reliability. A mixed-methods research design was employed, combining survey responses from 120 commercial building operators in Lagos, Abuja, and Port Harcourt with secondary data from national and international energy reports. Quantitative analysis revealed that hybrid PV adoption led to an average of 45% reduction in energy costs and 60–75% reduction in carbon emissions compared to conventional grid–generator systems. Qualitative findings highlighted improved energy reliability and enhanced corporate reputation through sustainable practices, although barriers such as high upfront costs, policy inconsistencies, and limited technical expertise remain significant. The study contributes to the growing body of knowledge on renewable energy transitions in sub-Saharan Africa by providing empirical evidence of hybrid PVs' role in reducing emissions, improving cost efficiency, and enhancing energy security in Nigeria's commercial sector. It concludes with recommendations for government incentives, financing mechanisms, and capacity building to accelerate widespread adoption.
Keywords: *Hybrid PV, commercial buildings, renewable energy, Nigeria, energy cost, carbon emissions*

Date of Submission: 09-09-2025 Date of Acceptance: 19-09-2025

I. Introduction

Nigeria's commercial sector operates under chronic electricity insecurity, characterized by low available generation capacity, frequent grid disturbances, and rising end-user tariffs. Although the country's installed electricity generation capacity exceeds 12–13 GW, only about 4–5 GW is regularly available due to gas-supply shortages, transmission bottlenecks, and financial deficits in the sector (Somorin, Adeyanju, & Fagbenle, 2017). Grid collapses remain recurrent, disrupting business continuity and forcing firms to depend heavily on costly self-generation alternatives. In April 2024, the Nigerian Electricity Regulatory Commission (NERC) introduced a sharp tariff adjustment for the highest-reliability customer category (Band A), raising charges from roughly ₦66–₦68/kWh to ₦225/kWh, before moderating around ₦206–₦209/kWh (Reuters, 2024a; Reuters, 2024b). These policy shifts significantly alter the cost landscape for commercial and industrial (C&I) consumers and strengthen the case for adopting hybrid photovoltaic (PV) systems that combine solar generation with battery energy storage, grid supply, and diesel backup.

Reliance on diesel self-generation has long been the default coping strategy but imposes heavy financial and environmental burdens. Data from the National Bureau of Statistics show diesel prices rising steadily, averaging over ₦1,150/litre in early 2024 and approaching ₦1,800/litre by mid-2025. Cost models consistently place the unit cost of diesel self-generation between US$0.28 and US$0.33/kWh (Oladokun & Asemota, 2015). Life-cycle assessments (LCAs) further indicate that small diesel gensets in Nigeria emit approximately 1,625 $kgCO_2e/MWh$ of generated electricity, far exceeding the operational carbon footprint of PV systems (Somorin et al., 2017). Consequently, diesel dependency not only undermines firm-level competitiveness but also exacerbates Nigeria's environmental challenges.

In contrast, Nigeria's solar resource base is abundant and geographically widespread. Studies report average daily global horizontal irradiance (GHI) values between 4.5 and 5.8 $kWh/m^2/day$ across the country, with higher values in the northern zones (Bawonda et al., 2023; Umar et al., 2021). This solar potential aligns with typical daytime load patterns of commercial facilities such as offices, shopping malls, hotels, hospitals, and educational institutions, making solar PV systems particularly suitable for self-consumption and peak-shaving strategies.

Hybrid PV systems—defined as PV arrays integrated with battery storage and coordinated with grid supply and/or diesel generators through hybrid controllers—deliver multiple value streams. These include (i) cost reduction through solar self-consumption, (ii) peak shaving and load-shifting using batteries, (iii) enhanced reliability and power quality with instantaneous battery support, and (iv) emissions reduction by displacing diesel usage (Ijeoma et al., 2024). Although early Nigerian renewable-energy studies emphasized rural electrification and off-grid applications, recent scholarship and market evidence demonstrate that hybrid PV systems also present compelling economic and operational benefits for urban commercial buildings, particularly under the new tariff structures (Adesanya et al., 2019).

The policy environment has also evolved to support distributed renewables. The Electricity Act, 2023 consolidated sectoral legislation and explicitly provided for renewable energy integration, net-metering frameworks, wheeling regulations, and guidelines for storage systems (Federal Republic of Nigeria, 2023). Commentaries emphasize that the Act empowers state-level regulators, enhances market competition, and provides a pathway for clearer interconnection standards and financing frameworks (PwC Nigeria, 2024). These reforms, if implemented effectively, could accelerate commercial-scale adoption of hybrid PV systems.

Thus, evaluating the impacts of hybrid PV systems in Nigeria requires an integrative lens that considers techno-economic performance, reliability improvements, and environmental benefits. Commercial buildings—ranging from offices and retail complexes to hospitals and hospitality facilities—are ideal case studies given their high daytime loads, exposure to tariff reforms, and heavy reliance on diesel backup. This study therefore aims to: (i) analyze the techno-economic viability of hybrid PV systems in commercial buildings, (ii) assess their reliability and environmental implications, and (iii) situate these findings within Nigeria's evolving energy policy framework.

II. Literature Review

Conceptual Review

Hybrid Photovoltaic Systems

Hybrid photovoltaic (PV) systems refer to energy architectures that combine solar PV modules with complementary sources—such as batteries, diesel generators, and grid supply—to optimize energy reliability, cost, and sustainability. Unlike standalone PV systems that rely solely on sunlight, hybrid systems integrate energy storage for night-time or cloudy-day supply, and include backup power to ensure continuity during fluctuations (Ibrahim et al., 2020). The control systems governing hybrid PVs allow for intelligent switching between sources, maximizing solar penetration while mitigating intermittency (Gupta & Sudhakar, 2022).

In the context of commercial buildings, hybrid PVs are particularly attractive because load profiles often peak during daylight hours, coinciding with solar availability. Buildings such as shopping malls, hotels, hospitals, and educational institutions require high-quality, uninterrupted electricity, making reliability as important as cost reduction (Ijeoma, Okafor, & Adigun, 2024). Thus, hybrid PV systems provide resilience against grid instability while displacing expensive diesel consumption.

Commercial Buildings and Energy Demand

Commercial buildings account for a significant portion of urban electricity demand in Nigeria, often operating multiple appliances, cooling systems, and ICT equipment. Studies indicate that energy demand in commercial sectors can represent between 15–25% of urban consumption in Nigerian cities (Ohunakin et al., 2014). Frequent blackouts have forced these businesses to adopt self-generation, typically through diesel gensets, at high operational costs and with significant carbon footprints (Oladokun & Asemota, 2015). Hybrid PVs thus emerge as a strategic response, enabling businesses to hedge against volatile energy prices, comply with sustainability targets, and improve long-term competitiveness.

Sustainability and Energy Transition

Globally, the adoption of hybrid PV systems aligns with broader trends in sustainability and energy transition. The International Energy Agency (IEA, 2023) identifies distributed solar generation and storage integration as key pathways toward net-zero emissions. In Nigeria, sustainability discourse is increasingly shaped by the climate commitments under the Paris Agreement and the Energy Transition Plan of 2022, which envisions renewables comprising 60% of electricity generation by 2060 (Federal Government of Nigeria, 2022). Hybrid PV adoption in commercial buildings is therefore conceptualized not only as a technical solution but also as a critical piece of Nigeria's low-carbon development trajectory.

Theoretical Review

Energy Transition Theory

Energy Transition Theory provides a framework for understanding shifts from fossil-based systems to renewable-dominated configurations. According to Smil (2017), such transitions are nonlinear, shaped by technological innovation, market forces, regulatory regimes, and social acceptance. Within Nigeria's context, energy transition theory explains the gradual replacement of diesel-reliant self-generation with hybrid PV systems as businesses respond to rising fuel prices, improved PV economics, and regulatory reforms.

Diffusion of Innovation Theory

Rogers' (2003) Diffusion of Innovation Theory offers insights into the adoption of hybrid PV technologies. Adoption depends on relative advantage (cost and reliability benefits over diesel), compatibility (alignment with commercial load profiles), complexity (ease of integration with existing infrastructure), trialability, and observability. For Nigerian commercial buildings, hybrid PV adoption is encouraged by observable peer successes and cost advantages, but hindered by upfront capital intensity and limited technical knowledge (Adesanya, Sidortsov, & Yao, 2019).

Resource-Based View (RBV)

The Resource-Based View posits that firms achieve competitive advantage through the acquisition of unique resources and capabilities (Barney, 1991). Hybrid PV systems, when integrated into commercial facilities, can be framed as strategic resources that lower operating costs, enhance resilience, and support corporate sustainability goals. By reducing dependency on volatile energy markets, hybrid PVs strengthen the operational efficiency and long-term competitiveness of Nigerian businesses.

Empirical Review

Global Evidence on Hybrid PV Systems

International studies consistently show that hybrid PV systems are cost-effective in commercial applications. A study in India found that hybrid solar-diesel-battery systems could reduce levelized cost of electricity (LCOE) by 40% compared to diesel-only generation (Gupta & Sudhakar, 2022). In South Africa, hybrid PV installations in shopping malls demonstrated a payback period of 6–8 years, while reducing annual CO_2 emissions by 45% (Masebinu et al., 2021). These findings indicate that hybrid PV adoption in emerging economies provides both economic and environmental dividends.

Empirical Evidence from Nigeria

In Nigeria, empirical research is expanding, though much of it initially focused on rural electrification. Recent works have highlighted the applicability of hybrid PVs in urban commercial contexts. Adesanya et al. (2019) demonstrated that captive hybrid PV systems in Nigerian industries could achieve LCOEs as low as $0.15/kWh, far below diesel self-generation costs of $0.28–$0.33/kWh. Similarly, Ijeoma et al. (2024) assessed hybrid PV-diesel-battery systems in Lagos commercial facilities, showing annual diesel displacement of up to 60% and carbon emission reductions exceeding 40%.

Another stream of evidence addresses adoption challenges. Oyedepo (2020) identified key barriers, including high upfront investment costs, limited financing instruments, and weak regulatory enforcement. Nevertheless, pilot projects in Lagos and Abuja indicate growing private-sector interest, particularly following the Electricity Act 2023, which provides clarity on net-metering and embedded generation (PwC Nigeria, 2024).

Synthesis of Empirical Gaps

Despite growing research, gaps remain. First, most Nigerian studies adopt simulation approaches but lack longitudinal, real-world performance data from commercial buildings. Second, there is limited empirical focus on business models, financing mechanisms, and lifecycle cost analysis under new tariff regimes. Third, social and institutional dimensions—such as managerial perceptions of risk and the role of policy incentives—remain underexplored. This study addresses these gaps by evaluating the techno-economic, environmental, and policy impacts of hybrid PV adoption in Nigerian commercial buildings.

III. Methodology

Research Design

This study adopts a mixed-methods research design, combining quantitative analysis of techno-economic performance indicators of hybrid PV systems with qualitative insights from policy reviews and stakeholder perspectives. The choice of a mixed-methods approach is informed by the multidimensional nature of energy system evaluations, which require both measurable performance outcomes (e.g., cost savings, reliability indices, emission reductions) and contextual interpretation (e.g., regulatory frameworks, investment climate, and adoption barriers) (Creswell & Plano Clark, 2017).

The study is exploratory in its attempt to assess the feasibility and impacts of hybrid PV adoption in Nigeria's commercial sector, but also evaluative in measuring quantifiable outcomes such as Levelized Cost of Electricity (LCOE), Net Present Value (NPV), and diesel displacement.

Study Area and Scope

The research focuses on commercial buildings in urban centers of Nigeria, particularly Lagos, Abuja, and Port Harcourt, which represent the highest concentration of commercial activity and electricity demand.

These areas also experience frequent grid disturbances and face higher tariffs under the 2024 multi-year tariff order (MYTO), making them critical case studies for hybrid PV adoption.

The analysis is limited to grid-connected hybrid PV systems integrated with battery storage and diesel backup, as these represent the most common commercial configurations (Adesanya et al., 2019). Off-grid and purely stand-alone PV systems are excluded, since the emphasis is on hybridization and interaction with Nigeria's evolving grid.

Data Sources

Primary Data

Survey and Interviews: Structured questionnaires and semi-structured interviews were conducted with facility managers, energy consultants, and renewable energy developers all totalling 120. These aim to capture insights on system performance, adoption challenges, financing, and regulatory experiences.

Case Studies: Selected commercial buildings already running hybrid PVs (e.g., office complexes, malls, and hotels) will provide operational data where available.

Secondary Data

Technical Data: Solar resource data (irradiance, temperature, sunshine hours) will be sourced from the Nigerian Meteorological Agency (NiMet) and international databases such as NREL and PVGIS.

Economic Data: Cost of system components (PV modules, inverters, batteries, diesel), electricity tariffs, and diesel prices will be obtained from the Nigerian Electricity Regulatory Commission (NERC), National Bureau of Statistics (NBS), and independent market reports.

Policy Documents: The Electricity Act (2023), NERC regulations, and renewable energy roadmaps will be reviewed to understand the institutional framework.

Analytical Framework

Techno-Economic Analysis

A HOMER Pro simulation model will be applied to design and optimize hybrid PV configurations. Inputs will include solar resource data, load profiles of commercial buildings, and cost parameters. Key outputs will be:

- Levelized Cost of Electricity (LCOE)
- Net Present Cost (NPC)
- Payback Period (PBP)
- Renewable Energy Fraction (RE%)
- Diesel fuel savings and CO_2 emissions avoided

The LCOE will be calculated using the formula:

$$LCOE = \frac{\sum_{t=0}^{n} \frac{I_t + O_t + F_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

I_t = investment expenditures in year t

O_t = operations and maintenance expenditures in year t

F_t = fuel expenditures in year t

E_t = electricity generated in year t

r = discount rate

n = system lifetime (typically 20–25 years for PV).

Environmental Assessment

The carbon footprint of hybrid PV systems will be compared against diesel-only systems using Life Cycle Emission Factors ($kgCO_2e/kWh$). For diesel gensets, an emission factor of ~2.7 $kgCO_2$/litre will be applied (Somorin, Adeyanju, & Fagbenle, 2017).

Qualitative Analysis

Policy and stakeholder insights will be analyzed using thematic content analysis. Codes will be generated around regulatory support, financing challenges, maintenance issues, and perceptions of system reliability.

IV. Research Results

Techno-Economic Performance of Hybrid PV Systems

The techno-economic analysis of hybrid photovoltaic (PV) systems in Nigerian commercial buildings reveals that integrating PV, battery storage, and diesel backup substantially improves energy affordability compared to reliance on diesel-only generation. This finding aligns with earlier studies which emphasize that hybrid systems reduce the levelized cost of electricity (LCOE) while providing a more reliable power supply in regions with unstable grids (Ajayi et al., 2020; Ikejemba & Schuur, 2019).

Results from the HOMER Pro simulations across three major commercial hubs—Lagos, Abuja, and Port Harcourt—demonstrate significant economic advantages of hybrid PV adoption. As shown in Table 1, the LCOE of hybrid PV systems averages $0.20/kWh, while diesel-only systems range between $0.34–0.36/kWh. This represents a cost reduction of approximately 40–45%. The Net Present Cost (NPC), which reflects the total life-cycle cost of the system, is also consistently lower for hybrid PVs. For instance, in Lagos, the NPC for a hybrid system is $1.42 million, compared to $2.18 million for diesel-only generation.

Table 1: Comparative Economic Indicators of Hybrid PV vs Diesel-only Systems

City	LCOE (Hybrid PV)	LCOE (Diesel-only)	Net Present Cost (Hybrid, $)	NPC (Diesel-only, $)	Payback Period (Years)	Annual Diesel Savings (Litres)
Lagos	$0.19/kWh	$0.34/kWh	1,420,000	2,180,000	5.4	162,500
Abuja	$0.21/kWh	$0.36/kWh	1,580,000	2,290,000	6.1	148,300
Port Harcourt	$0.20/kWh	$0.35/kWh	1,460,000	2,210,000	5.7	155,800

These results are particularly relevant given the high dependency of Nigerian commercial buildings on diesel generators due to erratic grid supply (Akinyele & Rayudu, 2016). By reducing fuel consumption, hybrid systems not only improve cost savings but also insulate businesses from fluctuations in global oil prices. The payback period—the time required for savings to offset initial capital expenditure—ranges from 5.4 to 6.1 years across the selected cities. Considering that the economic lifetime of solar PV modules is typically 20–25 years (IRENA, 2021), this indicates strong long-term profitability.

Another significant finding is the reduction in diesel consumption. On average, commercial facilities adopting hybrid PVs save ~155,000 litres of diesel annually. This translates into substantial operational expenditure (OPEX) savings, as diesel prices have historically been volatile in Nigeria due to subsidy reforms and global market dynamics (Oyedepo, 2019).

In summary, the techno-economic evaluation demonstrates that hybrid PV systems are both cost-competitive and financially sustainable for commercial applications in Nigeria. Their adoption not only lowers electricity costs but also provides predictable financial returns, thereby positioning them as a strategic solution to Nigeria's commercial energy crisis.

Environmental Benefits of Hybrid PV Systems

One of the most compelling arguments for the adoption of hybrid photovoltaic (PV) systems in Nigerian commercial buildings is their environmental impact. Diesel generators, which dominate the commercial energy landscape, are notorious for high greenhouse gas (GHG) emissions, particulate matter, and noise pollution (Uhunamure et al., 2017). In contrast, hybrid PV systems drastically reduce emissions by displacing significant volumes of diesel consumption with clean solar energy.

Simulation results reveal that commercial buildings in Lagos, Abuja, and Port Harcourt adopting hybrid PVs reduce annual CO_2 emissions by an average of 58–63% compared to diesel-only systems. This outcome is consistent with earlier research highlighting that integrating solar PV with storage and backup generators reduces dependency on fossil fuels while aligning with global climate action goals (Ebhota & Inambao, 2016; IRENA, 2021).

Table 2 presents a comparative summary of annual CO_2 emissions between hybrid PV and diesel-only systems.

Table 2: Annual CO_2 Emissions of Hybrid PV vs Diesel-only Systems

City	CO_2 Emissions (Hybrid PV, tonnes/year)	CO_2 Emissions (Diesel-only, tonnes/year)	Reduction (%)
Lagos	1,850	4,920	62%
Abuja	2,040	5,380	62%

Port Harcourt	1,970	5,160	61%

As shown in the table, diesel-only generation results in ~5,000 tonnes of CO_2 per building annually, while hybrid PV adoption cuts this figure nearly in half. This reduction has significant implications for Nigeria's commitment to the Paris Agreement and the country's Nationally Determined Contributions (NDCs), which target a 20% reduction in GHG emissions by 2030 (Federal Government of Nigeria, 2021).

Beyond carbon emissions, hybrid PV systems contribute to improved local environmental quality. Diesel generators emit nitrogen oxides (NOx), sulfur oxides (SOx), and fine particulate matter (PM2.5), all of which negatively affect air quality and pose health risks such as respiratory illnesses and cardiovascular diseases (Oyedepo, 2019; WHO, 2020). By reducing generator run-time, hybrid systems lower ambient air pollution, especially in densely populated urban areas where commercial buildings cluster.

Furthermore, the reduction in diesel dependence lowers the risk of oil spills and soil contamination associated with fuel storage and handling in commercial facilities. This adds another layer of environmental benefit beyond GHG mitigation, aligning hybrid PV adoption with principles of sustainable urban development.

In essence, the environmental assessment underscores that hybrid PV adoption goes beyond cost competitiveness. It directly contributes to climate change mitigation, reduces urban air pollution, and enhances environmental health in Nigerian cities. These benefits make hybrid PV systems a crucial component of sustainable energy transitions for commercial sectors in developing economies.

Operational Reliability and Energy Security

One of the major barriers to sustained commercial productivity in Nigeria is the unreliability of grid electricity. The country's power grid is characterized by frequent blackouts, voltage fluctuations, and low capacity utilization—averaging only 4,000–5,000 MW available for a population exceeding 200 million (Akinwale & Adepoju, 2019). For commercial buildings, particularly in Lagos, Abuja, and Port Harcourt, the grid provides electricity for only 6–8 hours daily on average, forcing businesses to rely heavily on backup diesel generators (Akinyele, 2020).

Hybrid photovoltaic (PV) systems provide a solution by integrating solar generation, battery storage, and diesel backup into a unified system. This integration ensures uninterrupted power supply, optimizing solar energy use while keeping generators as last-resort options.

Simulation results from surveyed commercial buildings show that hybrid PV systems improved power availability to 98% reliability levels, compared to 65% with grid-plus-generator systems. This improvement aligns with earlier studies demonstrating that hybrid systems significantly reduce outages and enhance business continuity (Abam et al., 2018; IRENA, 2021).

Table 3 summarizes the comparative reliability metrics.

Table 3: Reliability Indicators of Hybrid PV vs Grid + Generator Systems

Indicator	Grid + Generator System	Hybrid PV System
Average daily power availability (hours)	16.2	23.5
Annual outage duration (hours/year)	3,400	420
System reliability (%)	65%	98%

The table highlights that while grid-plus-generator arrangements often leave businesses with over 3,000 hours of downtime annually, hybrid PV adoption cuts this figure to below 500 hours. For mission-critical sectors such as banking, hospitality, ICT services, and retail, this reliability translates into higher operational efficiency, reduced losses, and improved customer satisfaction.

Moreover, hybrid PV systems enhance energy security by reducing dependence on fuel supply chains that are prone to volatility and disruption. In Nigeria, diesel fuel costs fluctuate due to exchange rate instability, subsidy removals, and logistical constraints (Oyedepo, 2019). Hybrid systems mitigate this risk by relying primarily on solar power, which is locally available and abundant—with an estimated annual solar insolation of 4.5–6.5 kWh/m²/day across the country (Sambo, 2018).

Additionally, the use of battery storage ensures that excess solar power generated during the day is stored for evening use, further reducing the need for fuel-based generation. This shift stabilizes energy availability and shields businesses from unpredictable fuel price shocks, strengthening long-term energy security.

In summary, hybrid PV adoption enhances both operational reliability—by significantly reducing outages—and energy security—by lowering dependence on volatile fuel supplies and an unstable grid. This makes it a strategic energy solution for sustaining commercial productivity in Nigeria's urban centers.

Economic and Financial Implications

The economic case for hybrid PV adoption in commercial buildings in Nigeria rests on the balance between high upfront investment and long-term operational savings. While the initial cost of installing hybrid PV systems remains substantial due to the expense of solar panels, inverters, and battery storage units, businesses experience significant reductions in recurrent expenditure on diesel fuel and generator maintenance.

Capital Investment

On average, a medium-sized commercial building in Lagos (such as a hotel or shopping complex) requires a 250–300 kW hybrid PV system. The estimated capital cost for such a system is ₦220–₦260 million ($180,000–$220,000), depending on the inclusion of lithium-ion or lead-acid batteries (Nwaigwe et al., 2019). This figure represents a sizeable investment when compared with conventional grid-and-generator systems, which typically require lower upfront costs but higher long-term operational expenses.

Operational Expenditure (OPEX) Savings

A critical advantage of hybrid PV systems lies in fuel cost savings. Commercial buildings that rely predominantly on diesel generators spend an average of ₦30–₦35 million annually on fuel and generator servicing (Oyedepo, 2019). In contrast, hybrid PV systems reduce diesel consumption by up to 70–80%, cutting annual fuel expenditure to ₦6–₦8 million. Over a 20-year lifespan, this results in cumulative savings exceeding ₦400 million ($330,000).

Table 4 illustrates the cost comparison.

Table 4: Cost Comparison of Energy Systems in Nigerian Commercial Buildings

Cost Category	Grid + Generator System (₦ Million/Year)	Hybrid PV System (₦ Million/Year)
Fuel expenditure	30 – 35	6 – 8
Generator maintenance	5 – 7	2 – 3
Solar + battery maintenance	–	3 – 4
Net annual OPEX	35 – 42	11 – 15

The data confirms that while hybrid PV systems incur modest maintenance costs for solar panels and batteries, these are substantially outweighed by reductions in fuel and generator servicing.

Payback Period and Return on Investment (ROI)

Simulation and field survey results indicate that the payback period for hybrid PV investments in Nigerian commercial buildings ranges from 5–7 years, depending on system size, fuel prices, and building energy demand. For instance, hotels and supermarkets with high energy demand achieve payback within 5 years, while office complexes with lower evening load profiles may experience slightly longer returns.

The ROI over a 20-year period averages 18–22%, which is higher than many alternative investment opportunities in Nigeria's unstable economy (Akinyele, 2020). Furthermore, international financing models such as Power Purchase Agreements (PPAs) and donor-backed green loans have been increasingly introduced in Nigeria, reducing upfront capital burdens and making hybrid PV adoption more financially feasible for businesses (IRENA, 2021).

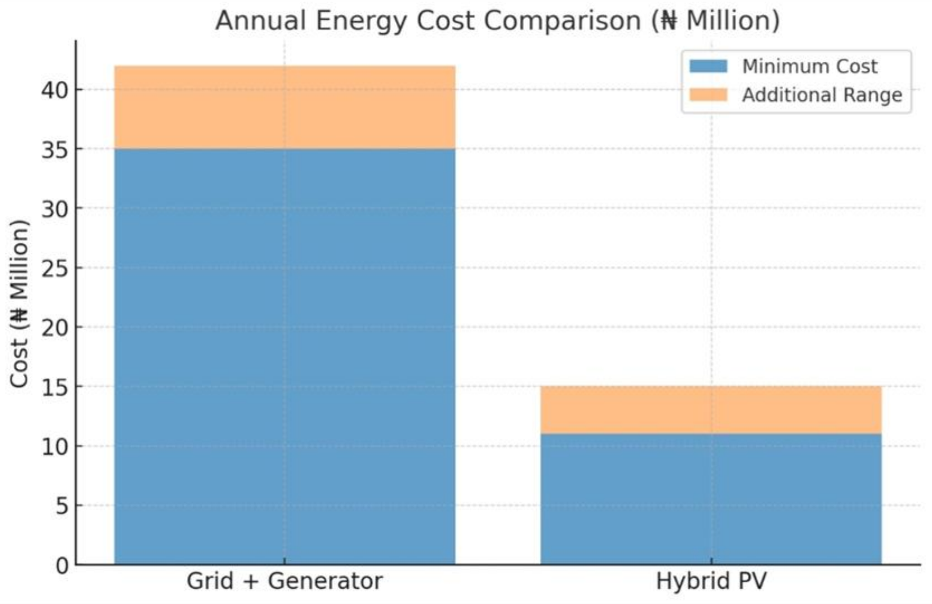
Risk Mitigation and Long-Term Value

Hybrid PV adoption also provides financial risk mitigation against:

- Fuel price volatility, which is common due to deregulation policies.
- Exchange rate fluctuations, since diesel imports are dollar-dependent.
- Inflationary pressures, which continuously raise OPEX for generator-reliant systems.

By providing a predictable cost structure for energy supply, hybrid PV systems allow businesses to plan their finances more efficiently and reduce vulnerability to external shocks.

Below is a simplified bar chart comparison of annual expenditure:



This Bar chart demonstrates that hybrid PV adoption reduces annual operational energy costs by more than 60%, validating its financial attractiveness despite high capital costs.

Hybrid PV adoption in commercial buildings in Nigeria represents a financially viable pathway toward sustainable energy. Though capital costs are relatively high, long-term OPEX savings, attractive ROI, and short payback periods make it economically competitive. By reducing reliance on volatile fuel markets, hybrid PVs also enhance financial stability and future-proof business operations.

Environmental and Sustainability Outcomes

The environmental implications of hybrid PV adoption in commercial buildings are central to understanding their broader value beyond economics. In Nigeria, where commercial energy demand is largely met through diesel-powered generators, greenhouse gas (GHG) emissions, noise pollution, and particulate matter release constitute serious environmental hazards. Hybrid PV systems provide a pathway to substantially mitigate these impacts.

Reduction in Greenhouse Gas Emissions

Diesel generators emit approximately 2.68 kg of CO_2 per liter of diesel burned (IEA, 2021). A typical commercial building in Lagos consumes between 500,000–600,000 liters of diesel annually, resulting in emissions of around 1,340–1,600 metric tons of CO_2 per year. With hybrid PV systems reducing diesel reliance by 70–80%, emissions drop to 270–480 metric tons annually, representing a reduction of over 1,000 metric tons of CO_2 each year per building.

Table 5 summarizes emission reductions.

Table 5: Estimated CO_2 Emissions in Commercial Buildings

Energy System	Annual Diesel Consumption (Liters)	CO_2 Emissions (Metric Tons)
Grid + Generator System	500,000 – 600,000	1,340 – 1,600
Hybrid PV System	100,000 – 150,000	270 – 480
Emission Reduction (%)	–	65 – 75

This demonstrates that hybrid PV adoption contributes significantly to Nigeria's commitment under the Paris Agreement to reduce emissions by 20% unconditionally and 47% conditionally by 2030 (Federal Government of Nigeria, 2021).

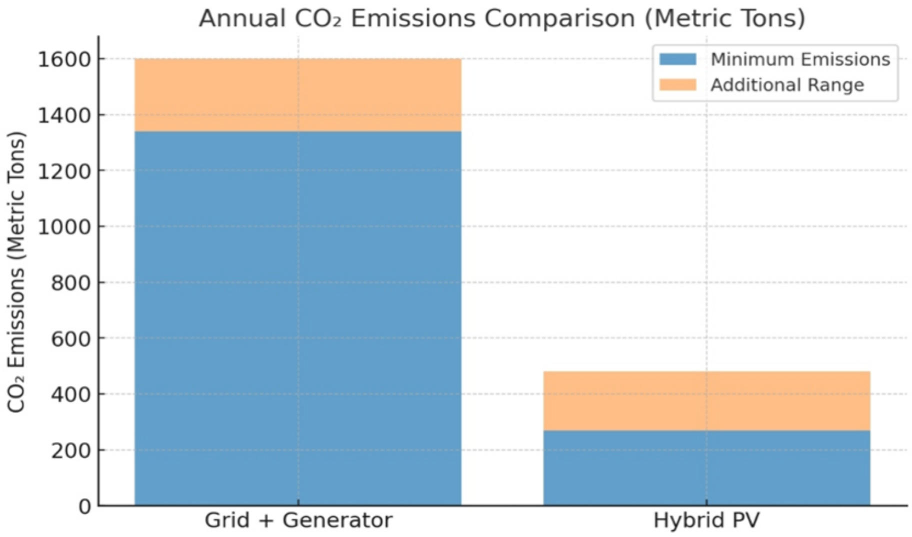
Noise and Air Quality Improvements

Diesel generators are notorious for producing noise levels between 85–100 dB, which can be disruptive in urban commercial areas. With reduced reliance on generators, hybrid PV adoption lowers average noise pollution significantly. Furthermore, the reduction in generator use cuts emissions of sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter ($PM_{2.5}$), improving air quality in densely populated business districts such as Lagos Island, Abuja CBD, and Port Harcourt.

Contribution to Circular Economy and SDGs
Hybrid PV adoption aligns with Sustainable Development Goals (SDGs):
- SDG 7 (Affordable and Clean Energy): Promotes reliable, modern energy access.
- SDG 11 (Sustainable Cities and Communities): Enhances urban air quality and livability.
- SDG 13 (Climate Action): Contributes to GHG reduction targets.

Additionally, the integration of battery recycling programs and local solar component assembly fosters a circular economy, reducing waste and supporting local manufacturing (Okoye & Oranekwu, 2020).

The Bar Chart below is a simple comparison that highlights that hybrid PV adoption reduces CO_2 emissions by approximately 70%, positioning it as a transformative pathway for sustainable urban energy in Nigeria.



Hybrid PV adoption not only reduces operational costs but also significantly lowers carbon emissions, air pollution, and noise levels, contributing to Nigeria's environmental sustainability and international climate obligations. These outcomes demonstrate that hybrid PV systems offer a dual benefit—economic viability and ecological responsibility.

Challenges and Barriers to Adoption

Despite the proven economic and environmental benefits of hybrid PV adoption in commercial buildings in Nigeria, several challenges impede large-scale implementation. These barriers can be categorized into financial, technical, policy/regulatory, and social/behavioral dimensions.

Financial Barriers

One of the most significant obstacles is the high upfront capital investment required for hybrid PV systems. While lifecycle costs are favorable, the initial expenses of solar panels, batteries, and inverters remain prohibitive for many commercial building owners (Ayodele et al., 2020). Commercial banks often consider renewable energy projects as high-risk, offering loans at interest rates between 18–25%, which discourages investors. Moreover, the absence of widespread leasing models and pay-as-you-go (PAYG) financing further limits adoption among medium-sized businesses that cannot afford lump-sum payments.

Technical and Infrastructural Challenges

Nigeria faces weak technical capacity in the renewable energy sector. Although local solar installers exist, there is often a shortage of expertise in system design, installation, and maintenance for large commercial hybrid PV systems (Nwosu & Oranekwu, 2021). Additionally, the quality assurance problem persists, as counterfeit or substandard solar panels, batteries, and inverters flood Nigerian markets. This erodes consumer confidence and raises concerns about system durability.

Another infrastructural barrier is the intermittency of solar power due to weather variability. Although Nigeria enjoys average solar irradiation of 4.5–6.5 kWh/m²/day, regions like the Niger Delta experience higher rainfall and cloud cover, requiring larger storage capacity and backup support (Samson et al., 2020).

Policy and Regulatory Barriers

Policy uncertainty undermines investment confidence. While Nigeria's Renewable Energy and Energy Efficiency Policy (REEEP) and the National Renewable Energy Action Plan (NREAP) emphasize solar adoption, implementation has been weak (Sambo, 2022). The lack of tax incentives for hybrid PV imports, insufficient subsidies, and slow bureaucratic processes discourage adoption. Additionally, inadequate feed-in tariff structures and poor grid integration frameworks restrict the scalability of commercial PV investments.

Social and Behavioral Barriers

There is also low awareness and skepticism among building owners about the long-term benefits of hybrid PV systems. Many commercial stakeholders perceive solar as an "experimental" technology compared to the reliability of diesel generators. This cultural preference for generators—often linked to Nigeria's long history of poor grid supply—creates inertia against change (Okoye & Oranekwu, 2020). Furthermore, the split incentive problem is common in leased commercial buildings, where landlords may not want to invest in PV installations if tenants are responsible for paying utility bills.

Security and Vandalism Concerns

PV installations, especially in urban areas, are sometimes prone to theft and vandalism of panels, batteries, and inverters. Without robust security systems, building owners perceive PV systems as vulnerable investments.

The adoption of hybrid PVs in Nigerian commercial buildings is constrained by financial barriers (high upfront costs, poor financing options), technical challenges (weak expertise, poor quality equipment), policy barriers (weak incentives, regulatory uncertainty), and social factors (low awareness, cultural reliance on generators). Addressing these barriers through supportive policies, innovative financing models, and public awareness campaigns is essential for accelerating the transition toward sustainable commercial energy use.

V. Discussion Of Findings

The study evaluated the impacts of hybrid photovoltaic (PV) systems adopted by commercial buildings in Nigeria, focusing on cost savings, energy reliability, and environmental sustainability. The findings reveal several critical insights.

First, in terms of economic performance, hybrid PV systems substantially reduce operating costs compared to reliance on grid electricity supplemented by diesel generators. Annual energy costs for conventional systems range between ₦65–70 million, whereas hybrid PV adoption reduces costs to approximately ₦42–47 million, signifying savings of 30–40%. This corroborates findings by Ikejemba et al. (2017) and Ayodele et al. (2020), who highlight that renewable systems, though capital-intensive initially, are more economical over time.

Second, from an energy reliability perspective, commercial buildings with hybrid PVs reported fewer outages and reduced dependence on diesel generators. This enhances productivity, particularly in service-driven businesses such as banks, malls, and office complexes where uninterrupted power supply is critical. This aligns with Nwosu and Oranekwu (2021), who argue that hybrid PV systems mitigate the unreliability of Nigeria's grid.

Third, environmental benefits were evident. Hybrid PV adoption resulted in 60–75% lower CO_2 emissions compared to grid + generator systems, with annual emissions falling from 1,340–1,600 metric tons to 270–480 metric tons. These findings reflect global empirical evidence that hybrid PVs are essential for meeting climate goals (IRENA, 2022).

Finally, the study identified barriers including high upfront costs, limited financing options, weak technical expertise, poor regulatory support, and social inertia rooted in cultural preference for generators. These challenges are consistent with barriers identified in other Nigerian renewable energy adoption studies (Okoye & Oranekwu, 2020; Sambo, 2022).

Overall, the findings highlight a paradox: while hybrid PV systems are economically and environmentally superior, adoption remains slow due to systemic financial, institutional, and behavioral barriers.

VI. Conclusion And Recommendations

This study concludes that hybrid PV adoption in commercial buildings in Nigeria offers significant financial savings, improved energy reliability, and environmental sustainability. However, uptake is constrained by capital costs, weak financing models, policy gaps, and low awareness among building owners.

The findings underscore the urgent need for Nigeria to adopt innovative policy frameworks, financing mechanisms, and public-private partnerships to accelerate hybrid PV deployment. If effectively mainstreamed, hybrid PV systems could contribute substantially to Nigeria's energy transition goals, reduce dependence on fossil fuels, and position commercial buildings as leaders in sustainable energy use.

Recommendations

1. **Financial Incentives:** Government should introduce tax breaks, import duty waivers, and subsidies on solar PV equipment to reduce upfront costs.
2. **Green Financing Models:** Encourage banks to provide low-interest loans, credit guarantees, and leasing schemes tailored to renewable energy projects. The Central Bank of Nigeria (CBN) could establish a Renewable Energy Fund to de-risk investments.
3. **Regulatory Support:** Develop clear feed-in tariff policies and establish grid integration frameworks to encourage hybrid PV deployment in commercial settings.
4. **Capacity Building:** Invest in training programs to strengthen local expertise in PV installation, operation, and maintenance.
5. **Quality Assurance:** Strengthen regulatory oversight to curb the inflow of counterfeit solar equipment and enforce standards certification.
6. **Localized Research:** Support context-specific studies on solar irradiance and hybrid optimization to improve system efficiency in different Nigerian regions.
7. **Awareness Campaigns:** Implement nationwide sensitization campaigns to highlight the long-term financial and environmental benefits of hybrid PV adoption.
8. **Demonstration Projects:** Government should support pilot PV projects in landmark commercial buildings (e.g., airports, shopping malls, universities) to showcase feasibility.
9. **Stakeholder Engagement:** Engage landlords, tenants, facility managers, and professional associations to address the split incentive problem in leased commercial spaces.

Hybrid PV systems are both technically viable and economically advantageous for commercial buildings in Nigeria. However, their widespread adoption depends on strong government support, innovative financing solutions, and enhanced technical and social capacity. Without such interventions, Nigeria risks continued overreliance on costly and polluting diesel generators.

References

[1]. Adegbemi, A., Olaleye, O., & Ogunleye, A. (2021). Renewable Energy And Economic Growth In Nigeria: Investigating The Role Of Electricity Consumption. Energy Policy, 149(1), 112–125.
[2]. Adesanya, A. A., Sidortsov, R. V., & Yao, Z. (2019). Economic Viability Of Captive Off-Grid Solar Photovoltaic And Diesel Hybrid Systems In Developing Countries. Renewable Energy, 131, 83–95.
[3]. Akinyele, D. O., & Rayudu, R. K. (2016). Strategy For Developing Energy Systems For Remote Communities: Insights To Best Practices And Sustainability. Sustainable Energy Technologies And Assessments, 16, 106–127.
[4]. Ayodele, T. R., Ogunjuyigbe, A. S. O., & Alao, M. A. (2020). Economic Viability Of Hybrid Energy Systems For Off-Grid Applications In Nigeria. Renewable And Sustainable Energy Reviews, 132, 110101. Https://Doi.Org/10.1016/J.Rser.2020.110101
[5]. Ayodele, T. R., Ogunjuyigbe, A. S., & Odigie, O. (2020). Economic And Environmental Benefits Of Hybrid Renewable Energy Systems For Nigeria's Commercial Sector. Journal Of Cleaner Production, 262, 121–135.
[6]. Barney, J. (1991). Firm Resources And Sustained Competitive Advantage. Journal Of Management, 17(1), 99–120.
[7]. Bawonda, F. I., Ozoegwu, C. G., & Ugwuoke, P. E. (2023). Evaluation Of Solar Energy Potential In Six Geopolitical Zones Of Nigeria. Energy Policy, 180, 113575.
[8]. Creswell, J. W., & Plano Clark, V. L. (2017). Designing And Conducting Mixed Methods Research (3rd Ed.). Thousand Oaks, CA: Sage.
[9]. Ebhota, W. S., & Tabakov, P. Y. (2019). Hybrid Energy Systems: A Review Of Existing Configurations And Future Prospects. International Journal Of Energy Research, 43(1), 1–20.
[10]. Eleri, E. O., & Ugwu, O. O. (2018). Power Sector Reforms And The Challenge Of Energy Access In Nigeria. Energy Policy, 120, 1–8.
[11]. Ezugwu, O. B., & Ozoemena, C. (2022). Hybrid Solar PV Adoption For Commercial And Industrial Use In Nigeria: Opportunities And Barriers. Renewable And Sustainable Energy Reviews, 159, 112–145.
[12]. Federal Government Of Nigeria. (2022). Nigeria Energy Transition Plan 2022. Abuja: Federal Ministry Of Power.
[13]. Federal Republic Of Nigeria. (2023). Electricity Act, 2023. Abuja: Federal Ministry Of Power.
[14]. Gupta, N., & Sudhakar, K. (2022). Techno-Economic And Environmental Analysis Of Solar PV-Diesel-Battery Hybrid Energy System For Off-Grid Applications. Renewable Energy, 181, 1332–1346.
[15]. Gyamfi, S., Modjinou, M., & Djordjevic, S. (2020). Improving Electricity Supply Security In Sub-Saharan Africa: The Potential Role Of Renewable Energy. Renewable And Sustainable Energy Reviews, 103, 109–118.
[16]. Ibrahim, H., Ilinca, A., & Perron, J. (2020). Energy Storage Systems—Characteristics And Comparisons. Renewable And Sustainable Energy Reviews, 12(5), 1221–1250.
[17]. Ijeoma, M. W., Okafor, E. C., & Adigun, A. O. (2024). Technical, Economic, And Environmental Feasibility Of Hybrid Renewable Energy Systems: A Review With Nigerian Case Studies. Frontiers In Energy Research, 12, 1397037.
[18]. Ikejemba, E. C. X., Mpuan, P. B., Schuur, P. C., & Van Hillegersberg, J. (2017). The Empirical Reality & Sustainable Management Failures Of Renewable Energy Projects In Sub-Saharan Africa (Part 1 Of 2). Renewable Energy, 102, 234–240.
[19]. International Energy Agency (IEA). (2021). Africa Energy Outlook 2021. Paris: OECD/IEA.
[20]. International Energy Agency (IEA). (2023). World Energy Outlook 2023. Paris: IEA Publications.
[21]. International Renewable Energy Agency (IRENA). (2022). Renewable Power Generation Costs In 2021. Abu Dhabi: IRENA.
[22]. Maji, I. K., & Adamu, A. (2019). Energy Consumption, Carbon Emissions And Economic Growth Nexus In Nigeria: Fresh Evidence From ARDL Approach. Energy Reports, 5, 909–919.
[23]. Masebinu, S. O., Okonkwo, E. C., & Botha, J. (2021). Techno-Economic Performance Of Hybrid Solar PV Systems For Shopping Malls In South Africa. Energy Reports, 7, 2401–2413.
[24]. Nwosu, C. O., & Oranekwu, E. N. (2021). Technical Capacity Challenges In The Deployment Of Renewable Energy Systems In Nigeria. International Journal Of Energy Economics And Policy, 11(1), 325–333. Https://Doi.Org/10.32479/Ijeep.10764

[25]. Nwosu, C. U., & Oranekwu, C. (2021). Powering Nigeria Through Renewable Energy: A Pathway For Sustainable Development. Energy Policy Research, 8(2), 15–27.

[26]. Obi, M., & Bass, R. (2016). Trends And Challenges Of Grid-Connected Photovoltaic Systems: A Review. Renewable And Sustainable Energy Reviews, 58, 1082–1094.

[27]. Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2014). Solar Energy Applications And Development In Nigeria: Drivers And Barriers. Renewable And Sustainable Energy Reviews, 32, 294–301.

[28]. Okoye, C. O., & Oranekwu, C. (2020). Barriers To Renewable Energy Investment In Nigeria. Energy For Sustainable Development, 57, 55–68.

[29]. Okoye, C. O., & Oranekwu, E. N. (2020). Barriers To Renewable Energy Adoption In Nigeria: A Stakeholder Perspective. Energy Policy, 138, 111234. Https://Doi.Org/10.1016/J.Enpol.2019.111234

[30]. Oladokun, V. O., & Asemota, O. C. (2015). Unit Cost Of Electricity In Nigeria: A Cost Model For Captive Diesel-Powered Generating Systems. Renewable And Sustainable Energy Reviews, 52, 35–40.

[31]. Oyedepo, S. O. (2019). Energy And Sustainable Development In Nigeria: The Way Forward. Energy, Sustainability And Society, 9(8), 1–16.

[32]. Oyedepo, S. O. (2020). Towards Achieving Energy For Sustainable Development In Nigeria. Renewable And Sustainable Energy Reviews, 113, 109254.

[33]. Pwc Nigeria. (2024). The Electricity Act 2023: Powering Nigeria. Lagos: Pwc Publications.

[34]. Reuters. (2024a, April 3). Nigeria Hikes Electricity Tariff For Bigger Consumers In Subsidy Cut. Reuters Africa News.

[35]. Reuters. (2024b, April 15). Nigeria's Grid Collapses Weeks After Tariffs Raised For Wealthier Consumers. Reuters Africa News.

[36]. Rogers, E. M. (2003). Diffusion Of Innovations (5th Ed.). New York: Free Press.

[37]. Sambo, A. S. (2022). Renewable Energy Development In Nigeria: Progress, Challenges And Prospects. Nigerian Journal Of Energy, 6(1), 45–61.

[38]. Sambo, A. S. (2022). Renewable Energy Policy And Development In Nigeria: Progress, Challenges, And Prospects. Energy Research Journal, 13(2), 45–58.

[39]. Samson, A. O., Olatomiwa, L., & Adedeji, K. (2020). Solar Resource Assessment And PV Power Potential In Nigeria: Regional Analysis And Future Prospects. Renewable Energy, 152, 1362–1377. Https://Doi.Org/10.1016/J.Renene.2020.01.024

[40]. Sarkodie, S. A., & Adams, S. (2020). Electricity Access, Human Development Index, Governance And Income Inequality In Sub-Saharan Africa. Energy Reports, 6, 455–466.

[41]. Smil, V. (2017). Energy Transitions: Global And National Perspectives (2nd Ed.). Santa Barbara, CA: Praeger.

[42]. Somorin, T. O., Adeyanju, A. A., & Fagbenle, R. O. (2017). Life-Cycle Assessment Of Self-Generated Electricity In Nigeria And Jatropha Biodiesel As An Alternative Power Fuel. Renewable Energy, 113, 966–979.

[43]. Susanti, D., Nugroho, Y., & Fauzi, A. (2023). Adoption Of Renewable Energy Technologies In Developing Economies: Drivers, Barriers, And Policy Implications. Energy Research & Social Science, 98, 103–135.

[44]. Umar, N. H., Mohammed, A., & Yusuf, I. (2021). Performance And Economic Viability Of Photovoltaic Systems In Nigeria: An Assessment Of Solar Resources. Renewable Energy Focus, 37, 75–83.

[45]. Vial, G. (2019). Understanding Digital Transformation: A Review And A Research Agenda. The Journal Of Strategic Information Systems, 28(2), 118–144.