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Optimising Rooftop PV Deployment through Energy Efficiency Retrofits: Evidence from Institutional Buildings in Uganda, Zambia, and Nigeria

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Abstract

Electricity access in Sub-Saharan Africa remains highly constrained, with grid instability and widespread reliance on diesel generators undermining both energy security and sustainability. As of 2023, nearly 600 million people still lack reliable electricity, while many grid-connected users experience frequent blackouts. In Nigeria, for instance, the national grid has collapsed over 140 times since 2013, forcing more than 80 million people to depend on expensive diesel power. Against this backdrop, decentralised rooftop solar photovoltaic (PV) systems offer opportunities for resilience, autonomy, and emissions reduction. Yet, when deployed in isolation, PV often results in oversized and less cost-effective systems if underlying building efficiency remains poor. This study examines the integration of PV with energy efficiency (EE) retrofits in institutional buildings across Uganda, Zambia, and Nigeria. Using DesignBuilder and Energy Plus simulations, combined with techno-economic analysis and policy review, we assess energy savings, financial returns, and policy enablers. Results show that EE interventions reduced demand by 35–47%, enabling smaller, optimally sized PV systems with positive net present values and payback periods under ten years. Case studies demonstrated potential for net-zero or even surplus generation under supportive regulatory frameworks. Despite proven feasibility, adoption is slowed by policy and financing barriers. The study recommends adaptive business models, third-party solar services, energy service companies, and hybrid financing in order to accelerate decentralised energy transitions across the region.

1. Introduction

Sub-Saharan Africa continues to struggle with delivering reliable, affordable, and sustainable electricity. Despite abundant solar potential, most countries remain dependent on centralised grids hampered by ageing infrastructure, insufficient capacity, and climate-related vulnerabilities, particularly in hydropower-dependent systems. Rapid urbanisation has further widened supply-demand gaps. Nigeria illustrates the depth of this crisis: with a population exceeding 230 million, its grid consistently provides only around 4 GW, forcing reliance on expensive diesel generators that undermine energy security, increase costs, and raise greenhouse gas emissions [1]. Decentralised solutions such as rooftop solar photovoltaic (PV) systems offer resilience, cost savings, and emissions reduction. Yet, when deployed in isolation, PV often results in oversized and less cost-effective systems due to inefficient baseline demand. Addressing inefficiency is therefore critical.

An integrated strategy combining PV with energy efficiency (EE) retrofits, such as insulation, shading, natural ventilation, efficient lighting, and smart HVAC controls optimises system design, reduces upfront costs, and improves financial returns. Global evidence shows that PV + EE approaches consistently outperform standalone PV in both technical and economic terms [2, 3]. However, research applying this model in Sub-Saharan Africa remains limited. This study addresses the gap through a comparative analysis of institutional buildings in Uganda, Zambia, and Nigeria, assessing technical viability, financial outcomes, and enabling policy frameworks.

2. Literature Review

2.1 Global Developments in Rooftop PV Deployment

Over the last two decades, rooftop solar PV has emerged as a leading technology for distributed generation in buildings. Declining equipment costs, improved panel efficiency, and rising concern over climate change have accelerated adoption in residential, commercial, and institutional sectors [4]. Countries such as Germany, Japan, and Australia now source a significant share of electricity from rooftop PV, enabled by policies like feed-in tariffs, net metering, tax incentives, and affordable financing [5]. These measures have lowered barriers and made small-scale PV highly attractive.

However, economics and solar availability alone do not guarantee success. System performance depends on integration with building energy demand and grid conditions. Evidence from Europe and Asia highlights that pairing PV with energy efficiency retrofits delivers superior results in both cost savings and emissions reduction [6, 7]. Reducing loads through insulation, efficient lighting, and modern appliances allows smaller PV systems to achieve stronger returns with reduced investment.

2.2 The PV–EE Synergy: Theory and Evidence

The interaction between energy efficiency (EE) measures and rooftop PV deployment has been widely studied, with both theory and practice confirming their complementarity. Building energy simulations show that reducing baseline demand through efficiency upgrades allows smaller PV systems to be installed, lowering capital costs and improving overall financial returns [2]. Passive strategies such as shading, natural ventilation, and insulation reduce heating and cooling loads, while active upgrades including LED lighting and smart HVAC controls cut electrical consumption for lighting and air conditioning [8].

These interventions reduce both peak demand and total energy use, a benefit especially relevant in hot climates such as Sub-Saharan Africa where cooling dominates electricity demand [9]. Lower peaks also reduce the PV and storage capacity required for reliable supply. Beyond physical retrofits, behavioural and operational measures such as occupant training, automated controls, and optimised equipment schedules can deliver additional savings at low cost [10].

Evidence from Europe and the United States shows that zero-energy building programmes often adopt an “efficiency-first” principle, requiring stringent efficiency benchmarks before renewables are added [3]. Collectively, the research underscores that PV and EE work best in tandem: efficiency maximises the share of demand met by PV while improving the economic case for investment.

2.3 Rooftop PV and Energy Security in Sub-Saharan Africa

In Sub-Saharan Africa, the drivers for rooftop PV adoption differ markedly from those in industrialised economies. While sustainability goals and policy incentives dominate in Europe or North America, in Africa the key motivations are energy access and reliability [11]. Nearly 600 million people remain

without electricity, with rural areas most affected. Even in urban centres, supply is highly unreliable. Countries such as Nigeria, Ghana, Uganda, and South Africa experience frequent load shedding and blackouts [12]. In Nigeria, repeated grid collapses have forced institutions and businesses to depend on diesel generators, which are both expensive and polluting [13]. In many facilities, fuel costs consume a substantial share of operating budgets.

Rooftop PV deployment is growing but remains fragmented. South Africa has seen rapid uptake in response to persistent outages, and Kenya has pioneered solar home systems for rural households [14]. Yet most projects remain small-scale pilots rather than coordinated national strategies. Technical feasibility is rarely in doubt, given Africa's abundant solar resource; instead, the main barriers are institutional and financial, including limited access to affordable finance, shortages of skilled personnel, weak policy frameworks, and fragile supply chains [15]. Public and institutional buildings offer especially strong potential. Their large roof areas, predictable demand, and critical service functions make them ideal for PV integration, particularly when paired with energy efficiency retrofits and supported by enabling policies [16].

To overcome financial barriers, business models tailored to local conditions are essential. Power Purchase Agreements (PPAs) are gaining traction in Uganda, where private firms install and own PV systems and sell electricity to host institutions at rates below grid or diesel alternatives [17]. Zambia has piloted Integrated Energy Service Company (IESCo) models, bundling PV, efficiency retrofits, and maintenance, with repayment tied to savings as reported by Samunete [18]. Nigeria has tested hybrid public–private partnerships in universities and hospitals, leveraging donor or public funds to reduce investor risk [19]. Ultimately, scaling these models requires stable, supportive policy frameworks. Net metering, feed-in tariffs, tax incentives, and concessional financing can reduce risk, while policy uncertainty undermines investment [20]. Clear regulations remain critical to moving rooftop PV from isolated pilots to widespread adoption.

2.4 Simulation Tools and Comparative Methodologies

Building energy modelling and PV simulation tools are essential for assessing building performance and renewable integration. Software such as DesignBuilder with EnergyPlus, TRNSYS, or HOMER enables detailed analysis of thermal loads, lighting, equipment use, and solar generation under specific climatic and operational conditions [18]. These tools support scenario testing, such as evaluating the impact of insulation upgrades or sizing PV systems against demand. While widely applied in developed regions, Sub-Saharan African studies often rely on basic feasibility estimates due to data and skills limitations.

Most existing work focuses on single-building cases, typically examining technical feasibility or payback, with little cross-country comparison. Where comparative studies exist, they often rely on generic prototypes and inconsistent metrics, restricting broader insights. This research addresses that gap by applying a unified simulation framework to three institutional buildings in Uganda, Zambia, and Nigeria, using real operational data to ensure comparability and highlight how climate, building stock, and policy conditions influence PV + EE outcomes [18, 16].

2.5 Research Gaps and Study Contribution

The review of existing literature reveals three key gaps. First, there is a lack of integrated studies examining the combined impact of rooftop PV and energy efficiency retrofits in Sub-Saharan African buildings. Most research considers either PV adoption or efficiency measures in isolation, without exploring their interaction in real-world institutional contexts. Second, cross-country comparative analyses remain limited. Few studies apply consistent simulation tools and metrics across multiple African countries, making it difficult to evaluate how variations in climate, building stock, and policy environment affect outcomes. Third, there is insufficient attention to business models and regulatory frameworks. Technical feasibility has been well demonstrated, but limited work investigates how financing mechanisms, ownership models, or supportive policy conditions influence scalability and long-term success.

This study addresses these gaps through a comparative assessment of institutional buildings in Uganda, Zambia, and Nigeria. Using a consistent methodology and standardised metrics, it integrates building simulations, financial analysis, and policy review. The findings provide empirical evidence on how PV and EE interact in African contexts, highlighting both the performance benefits and the practical challenges. Beyond validating the PV + EE concept, the research identifies context-specific drivers and barriers, and proposes adaptive business models and policy reforms to bridge the gap between technical potential and real-world implementation.

3. Methodology

3.1 Research Design

This study adopts a comparative case study design to assess the integration of rooftop photovoltaic (PV) systems with energy efficiency (EE) retrofits in institutional buildings. Three Sub-Saharan African countries—Uganda, Zambia, and Nigeria—were selected, each represented by a building case. A mixed-methods approach combined building energy simulations and financial modelling with qualitative policy review, enabling both technical benchmarking and contextual analysis. Case selection followed consistent criteria: (i) the building served an institutional or commercial function, (ii) it was located in an urban or peri-urban area with grid reliability challenges, (iii) operational and architectural data were available, and (iv) potential existed for both PV and EE measures. The cases included an existing office building in Uganda, a new institutional facility in Zambia, and a retrofitted academic block in Nigeria. This diversity of climate, age, and baseline conditions allowed the study to generate comparative insights into the technical and policy dimensions of PV + EE adoption.

3.2 Case Study Selection

Three institutional buildings were selected to represent varied contexts in Sub-Saharan Africa.

In **Uganda (Kampala)**, *Crusader House*, a multi-story office complex, frequently depends on diesel generators due to unreliable grid supply. With high baseline energy use and strong retrofit potential, it reflects the challenges of many urban offices facing high costs and supply insecurity as stated by Migisha [16].

In **Zambia (Lusaka)**, the *Engineering Institution of Zambia (EIZ) Office* represents a newly constructed, partially energy-conscious facility. With ample roof space and provision for solar integration, it illustrates the advantages of incorporating PV and EE considerations at the design stage [18].

In **Nigeria (Lokoja)**, the *School of Environmental Technology, Kogi State Polytechnic* is an older academic block with basic retrofits in place. Despite inefficient baseline performance, its large roof and motivated stakeholders highlight opportunities for passive improvements in hot climates [21]. All buildings provided suitable roof areas, operational data, and architectural details, ensuring reliable simulation and financial analysis.

3.3 Energy Simulation

Energy simulations for each case building were conducted using DesignBuilder with EnergyPlus, a widely validated combination in building energy research [7]. The models incorporated geometry, construction materials, occupancy schedules, lighting, equipment loads, and HVAC systems. Architectural plans were digitised, and data on materials and operations were gathered from audits and facility managers. Where information was incomplete, standard assumptions or comparable buildings were used. Local climate data were integrated through Typical Meteorological Year (EPW) files for Kampala (Uganda), Lusaka (Zambia), and Lokoja (Nigeria), capturing hourly temperature, humidity, and solar radiation.

Two scenarios were simulated: Baseline (current performance) and Post-retrofit (with passive and active efficiency measures). Outputs included annual energy use by end-use, hourly load profiles, and peak demand. To ensure accuracy, simulated results were compared with utility bills, generator fuel logs, and metered data [19]. Calibration adjustments, such as infiltration rates or equipment densities, were applied before estimating retrofit savings and sizing rooftop PV systems.

3.4 Rooftop PV System Design

Based on the reduced post-retrofit demand profiles, rooftop PV systems were designed to meet a substantial share of each building's annual electricity needs. The goal was to balance demand coverage with technical and financial feasibility, avoiding excessive oversizing in contexts lacking mature feed-in tariffs or storage [6]. System design considered several parameters. Usable roof area was first assessed, excluding shaded zones, obstructions, and access pathways, to determine maximum feasible capacity. Local solar resource data were then drawn from meteorological files and NASA maps [22]. Kampala and Lusaka receive high, stable irradiance year-round, while Lokoja experiences slightly lower levels with seasonal variation. Panel orientation and tilt were set close to latitude angles, using existing roof slopes where favourable. Panels were oriented north in Uganda and Zambia (southern hemisphere) and south in Nigeria (northern hemisphere) to maximise output.

Standard derating factors accounted for inverter inefficiencies, wiring losses, dust accumulation, and temperature effects [23]. Annual PV generation was estimated by multiplying system capacity by the local yield factor, adjusted for these losses, and compared against demand profiles. Iterative sizing ensured systems supplied most of the load without excessive surplus. All systems were designed as grid-tied, assuming future net metering or export, while battery storage was excluded due to cost and complexity.

3.5 Financial Assessment

To assess the economic feasibility of rooftop PV after EE retrofits, a techno-economic analysis was conducted for each case using four indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and Return on Investment (ROI). NPV measured lifetime savings relative to initial costs, IRR indicated the discount rate at which NPV equals zero, payback estimated the time to recover capital outlay, and ROI expressed lifetime profit as a percentage of investment [2]. Country-specific cost inputs were applied. PV capital costs ranged from 800–1200 USD/kW, higher in Uganda and Nigeria due to import costs, but lower in Zambia given Southern African market access (Agyekum et al. [11]). Retrofit costs (lighting, HVAC upgrades) were also included. Energy savings were valued at prevailing tariffs about 0.15 USD/kWh in Uganda, 0.10 USD/kWh in Zambia, and 0.12 USD/kWh in Nigeria, - plus reduced diesel use where generators were displaced. O&M costs were set at 1–2% annually, with inverter replacement assumed in year ten. Discount rates reflected risk profiles: 8–10% for Uganda and Zambia, and 12% for Nigeria. A 20–25 year project horizon matched PV lifespans, with modest energy price escalation included. Comparisons with and without EE showed consistently stronger outcomes when integrated. EE reduced demand, optimised PV sizing, and significantly improved NPV, IRR, ROI, and payback performance.

3.6 Policy and Institutional Analysis

Recognising that technical feasibility and financial viability alone do not ensure implementation, this study also assessed the policy and institutional frameworks influencing rooftop PV and EE adoption in Uganda, Zambia, and Nigeria. Two qualitative methods were applied. First, document and literature review was undertaken, focusing on national energy policies, renewable energy action plans, regulatory codes, building standards, and incentive schemes [20, 13]. Reports from international agencies such as IEA [22] and IRENA [14] provided complementary insights. The review identified enabling factors (e.g., net metering, tax exemptions, public sector energy-saving mandates, green financing schemes) and gaps where policies were absent or weakly enforced.

Second, semi-structured interviews (N = 12) were conducted with facility managers, regulatory officials, and local solar developers across the three countries. These offered practical perspectives on approval processes, financing challenges, and perceptions of policy enforcement. Interviews were conducted under an ethics protocol, with informed consent, professional focus, and anonymity assured. The qualitative data were thematically coded around regulatory enablers and barriers, financing and incentives, institutional capacity, and market awareness. Triangulation with simulation and financial

results revealed mismatches between theoretical viability and practical constraints. For example, a financially attractive project might be undermined by the absence of a net metering framework or by limited institutional capacity to access financing.

3.7 Data Validation and Reliability

Several measures were taken to ensure the validity and reliability of this research. Energy models were calibrated against actual consumption data were available, with adjustments made until baseline simulations were within approximately 5–10% of recorded usage [19]. Financial models were also sensitivity-tested for uncertain variables such as discount rates, tariff escalation, and fuel costs [17]. By modelling alternative assumptions, we confirmed that the findings remained robust within reasonable parameter ranges. Data sources were cross-verified wherever possible. For example, information from utility bills was compared with generator fuel logs, and policy details mentioned in interviews were checked against published regulations. Applying a consistent set of modelling tools and assumptions across all three cases further strengthened the reliability of cross-country comparisons.

Ethical standards were carefully observed. Proprietary building information was accessed with permission and treated confidentially; specific building names are reported only where consent was granted as part of academic collaborations. The interview process followed institutional ethical protocols, with informed consent obtained and participant anonymity assured. By integrating rigorous quantitative modelling with qualitative contextual insights, the methodology not only quantified outcomes but also explained the institutional factors shaping them, laying the foundation for the subsequent results and discussion.

4. Results and Discussion

4.1 Energy Demand Reduction and PV Potential

Baseline vs. Post-Retrofit Energy Use

Across the three case studies, baseline annual energy consumption differed based on building size and usage patterns, but all were significantly reduced after implementing the suite of energy efficiency interventions. Table 1 summarizes the annual energy demand before and after retrofits, alongside the estimated annual energy output from the proposed PV systems and whether the building could achieve surplus energy (feed back to the grid) under those conditions.

Table 1
Energy Demand and Rooftop PV Output Estimates

Country	Baseline Demand (kWh/year)	Post-Retrofit Demand (kWh/year)	Estimated PV Output(kWh/year)	Surplus Potential
Uganda (Office)	291,127 *(Grid + Diesel)*	100,723	124,329	Yes – Grid feedback possible (excess generation)
Zambia (Office)	287,707	186,904	250,423	Yes – Net-zero feasible (generation ≥ demand)
Nigeria (Academic)	221,450	138,300	160,100	Near Net-Zero (minimal shortfall)
Source: Author's Compilation, 2024				

In Uganda's Crusader House, the baseline annual demand of approximately 291 MWh was supplied through a mix of grid electricity and heavy reliance on diesel generators during outages. Following extensive EE retrofits, the modelled demand fell to around 101 MWh, a 65% reduction. A rooftop PV system sized to the available roof could generate about 124 MWh annually, meeting the reduced load and potentially exporting roughly 23 MWh to the grid if net metering were permitted [16]. Under such conditions, the building could act as a net energy producer at times.

In Zambia's EIZ office, the baseline demand was around 288 MWh/year. Post-retrofit demand declined to 187 MWh, a 35% reduction. The proposed PV system, generating about 250 MWh/year, would comfortably cover annual demand and enable the building to achieve net-zero energy status [18], with surplus electricity available for export under supportive policy frameworks.

In Nigeria's academic building, baseline demand was 221 MWh/year, reduced to 138 MWh after retrofits (a 38% cut). The rooftop PV system could generate about 160 MWh annually, nearly meeting the total demand. While slightly short of full net-zero, this outcome demonstrates the potential of upgrading older infrastructure and pairing it with PV to significantly reduce dependence on grid supply and diesel generators [21]. Overall, results confirm that EE retrofits are foundational, cutting energy use by one-third to two-thirds. Downsized PV systems can then meet most or all remaining demand, enabling buildings to approach or achieve net-zero status.

Energy Efficiency Intervention Impact

Each case study implemented a tailored mix of passive, active, and behavioral measures to achieve the above-mentioned demand reductions. Table 2 provides a summary of the key EE interventions applied in each building, categorized by type.

Table 2
Summary of Energy Efficiency Interventions by Category

Category	Uganda (Office)	Zambia (Office)	Nigeria (Academic)
Passive Measures	External shading devices; Enhanced natural ventilation (operable windows)	Added roof insulation; Low-emissivity glazed windows; Sunshade louvres on facades	Cross-ventilation by opening new vents; Solar-reflective window film/glazing to reduce heat gain
Active Measures	Replaced all lighting with LED fixtures; HVAC zoning and scheduling (turned off in unused areas)	Daylight sensors for lighting; Variable-speed drives on HVAC fans and pumps for efficiency	Retrofitted old fluorescent lights with LEDs; Upgraded to high-efficiency air conditioners and improved controls
Behavioral/Operational	Staff awareness campaign on energy saving; Implemented manual equipment scheduling/shut-off routines (e.g., turning off AC after work hours)	Introduced automation for lighting (occupancy sensors) and stricter after-hours shutdown policies; Training for facilities staff on energy management	Conducted educational workshops for faculty/students on energy conservation; Appointed energy monitors to ensure lights/equipment are off when not needed

Source: Authors Compilation, 2024

The impact of energy efficiency measures varied across the three cases, reflecting differences in building design and baseline conditions. Passive strategies proved especially effective in Uganda and Nigeria, where thermal loads were high. In Kampala's tropical climate, shading devices and improved ventilation significantly reduced cooling energy, while in Nigeria reflective glazing lowered solar heat gains in classrooms. Zambia's newer office already incorporated some passive design, yet additional insulation and upgraded windows improved comfort and reduced air-conditioning demand. Active measures delivered consistent benefits across all countries. LED lighting retrofits reduced lighting energy by more than 50% in some buildings, with the added benefit of lowering cooling loads due to reduced waste heat. HVAC upgrades were highly effective: in Uganda, zoning prevented cooling of unoccupied floors, yielding substantial savings; in Zambia, variable speed drives enabled finer load control; and in Nigeria, replacing old units with efficient models sharply cut cooling demand.

Behavioural interventions were harder to quantify but still relevant. In Uganda and Nigeria, switching off equipment after hours and modest thermostat adjustments reduced consumption by an estimated 5–8%. Zambia relied more on automation, though staff training ensured optimal operation. Nigeria's educational setting fostered strong engagement from staff and students, reinforcing long-term behavioural change. Overall demand reductions were notable: Uganda achieved ~ 47%, Nigeria ~ 38%, and Zambia ~ 35%. Uganda's higher savings reflect both greater inefficiencies and intensive retrofits,

while Zambia's smaller percentage demonstrates that even modern, relatively efficient buildings can yield substantial improvements through targeted upgrades and operational tuning.

Financial Viability of Rooftop PV Systems

The techno-economic analysis of the integrated EE + PV projects showed robust financial performance for all three cases. Table 3 summarizes key financial metrics for each country case. All monetary values are in US dollars (USD) except NPV, which is shown in local currency for context.

Table 3
Financial Performance Summary of PV + EE Integration

Country	Total System Cost (USD, PV + key EE)	Payback Period (years)	Internal Rate of Return (IRR) (%)	Net Present Value (NPV) (local currency)
Uganda	$115,000	7.6 years	~ *26% IRR* (ROI ~ 265%)	UGX 179 million NPV *(Uganda Shillings)*
Zambia	$95,000	9.0 years	~ *18% IRR* (ROI ~ 518%)	ZMW 623,344 NPV *(Zambian Kwacha)*
Nigeria	$104,000	6.8 years	~ *28% IRR* (ROI ~ 432%)	NGN 28 million NPV *(Nigerian Naira)*
Source: Authors Compilation, 2024				

All three projects demonstrated payback times well within the typical 10–15 year lifetime of PV systems, confirming strong economic viability. Uganda's case achieved payback in approximately 7.6 years, driven by high baseline electricity and diesel costs. Every kWh saved or generated displaced an expensive alternative, leading to rapid savings. The net present value (NPV) was strongly positive at 179 million UGX, underlining its financial soundness.

Zambia's project paid back in about 9.0 years, slightly longer but still attractive for institutional investments. The return on investment (ROI) over the project life exceeded 500%, reflecting modest incremental retrofit costs and substantial long-term savings. With an internal rate of return (IRR) of ~ 18%, well above prevailing loan rates, the project represents a viable opportunity if financing is accessible. Nigeria's case delivered the fastest payback, around 6.8 years, due to heavy reliance on costly diesel generation. Once PV and EE measures were implemented, diesel consumption fell sharply, producing immediate savings. The IRR of ~ 28% and positive NPV of 28 million NGN confirm the financial advantage of displacing diesel and high-tariff grid electricity.

It should be noted that these results assume functional policies such as net metering or fair compensation for surplus generation. Without such mechanisms, financial outcomes would be less favourable. Overall, the analysis highlights that integrating EE retrofits with PV greatly improves viability compared to PV-only projects. By first reducing demand, system sizes were optimised and every solar kWh utilised, turning previously marginal projects into financially compelling investments.

Policy Environment and Market Readiness

The review of each country's policy and market environment revealed differences in how supportive or prepared they are for scaling rooftop PV and energy efficiency in institutional buildings. Table 4 provides a comparative snapshot of key aspects (net metering policy, building energy codes, financing availability, and prevalent business models).

Table 4
Policy and Market Conditions in the Three Countries

Aspect	Uganda	Zambia	Nigeria
Net Metering	Pilot stage; not yet fully operational in practice. Regulations drafted but limited implementation.	Under development; a framework announced but not widely executed yet.	Fragmented pilots only; no nationwide net metering. Some states/utilities experimenting in 2024.
Building Energy Codes	Code exists but weakly enforced. Few mandates for EE retrofits; compliance is low.	Green building guidelines emerging; code updates in progress for efficiency but early stage.	No enforceable national energy code for buildings yet; efficiency largely voluntary.
Financing Access for PV/EE	Very limited. Projects mostly rely on donor grants or special programs. Local banks rarely finance solar for institutions.	Moderate access via REFiT programs and some development bank lines. A few local banks starting to offer solar loans.	High capital barriers; few tailored financing schemes. Some government grants for universities, but private financing is scarce.
Suitable Business Model Prevalence	Third-Party Solar Service (PPA) models piloted (e.g., solar companies selling power to universities). Promising but scale is small so far.	Integrated ESCO (IESCo) models being tried (one-stop EE + PV contracts). Early stages, backed by donor projects.	Public-Private Partnerships (PPP) and hybrid leasing models discussed; a few examples in federal institutions with support, but not widespread.

Source; Authors Compilation, 2024

Comparative analysis shows Zambia slightly ahead in aligning policy with rooftop PV and EE adoption. It has initiated net metering discussions, is considering energy codes, and has piloted integrated energy service companies to bundle solutions. Implementation remains limited, but a visible roadmap exists. Uganda demonstrates innovation through private-sector solar service companies that finance installations, yet these operate in a weak policy environment: net metering is not fully functional, and efficiency standards are absent. This leaves scaling dependent on entrepreneurial initiatives rather than regulatory support. Nigeria lags furthest, lacking net metering, efficiency codes, or effective financing mechanisms. The Electricity Act (2023) could empower states and diversify the sector, but enforcement remains uncertain.

Stakeholder interviews reinforced these contrasts. Ugandan developers expressed frustration at the inability to export surplus power, reducing viability. Zambian officials reported new building codes under review and banks partnering with DFIs to provide concessional loans. In Nigeria, universities rely on capital grants, while private developers depend on foreign funding for limited “no-upfront-cost” projects, which cannot scale without local finance.

Overall, Zambia shows emerging policy momentum, Uganda offers entrepreneurial solutions needing stronger support, and Nigeria requires fundamental regulatory and financial reforms. The findings confirm that enabling environments are decisive for translating technical potential into implementation.

Cross-Case Insights

Comparison of the three case studies highlights several broader lessons for Sub-Saharan Africa’s energy transition.

Energy efficiency as a foundation. Across Uganda, Zambia, and Nigeria, EE retrofits were the essential step that made rooftop PV both technically feasible and financially attractive. By reducing demand, particularly cooling loads PV systems could be downsized, lowering upfront costs while ensuring reliable supply. This underscores that an “efficiency-first” approach is as critical in African contexts as in high-income countries.

Financial attractiveness of PV + EE. Despite differing conditions, all cases showed strong economics, with lifetime ROIs above 250% and payback periods under 10 years. In Uganda and Nigeria, where diesel generators had been a major cost burden, the combined approach yielded particularly dramatic savings. These results challenge the perception that renewables are unaffordable in Africa, showing instead that efficiency-led PV investments can outperform the status quo.

Policy gaps as bottlenecks. The greatest barrier to scaling is not technology but governance. Weak or absent net metering prevents surplus solar from being monetised, reducing project viability. Lax building codes allow inefficient construction to persist, while limited access to concessional finance restricts even cost-effective projects. Closing these policy and institutional gaps is vital to move beyond isolated pilots.

Localised business models. Uganda’s private solar service companies, Zambia’s integrated energy service models, and Nigeria’s potential for PPPs each demonstrate that context matters. No single model will succeed everywhere; instead, solutions must align with local financing ecosystems, institutional capacity, and stakeholder trust. International donors and investors should therefore support a portfolio of models rather than pushing uniform approaches.

Taken together, the cases suggest a pathway: begin with efficiency, demonstrate bankable PV + EE projects, then advocate for enabling policies and scale up with tailored financing models. This sequence could accelerate sustainable energy transitions across similar African contexts.

Discussion

Feasibility of PV + EE Integration in Sub-Saharan Institutional Buildings

The three case studies demonstrate that integrating rooftop PV with targeted energy efficiency (EE) retrofits provides a feasible and scalable pathway toward near net-zero energy performance in Sub-Saharan African institutional buildings. Despite differences in climate, building age, and grid conditions, all cases achieved substantial demand reductions and favourable financial outcomes, confirming that both new and existing facilities can transition into low-carbon buildings when efficiency and renewable are combined [2, 6].

Uganda's office case, starting from a diesel-dependent and inefficient baseline, highlights the transformative potential of addressing waste before installing solar. EE retrofits reduced demand by nearly two-thirds, enabling a modest PV system to cover most needs and even export surplus in favourable conditions [16]. This shift from heavy diesel reliance to potential clean energy exporter illustrates the scale of untapped opportunity in poorly managed buildings.

Zambia's newly constructed office underscores the value of integrating PV and efficiency at the design stage. With provisions for solar and basic efficiency already embedded, achieving net-zero was straightforward and cost-effective [18]. This case shows that foresight in new builds, such as solar-ready roofs and efficient envelopes, can enable institutions to leapfrog to sustainable operations with minimal additional cost. Nigeria's older academic building, despite weak policy support and outdated infrastructure, still approached net-zero with strong economic returns. This outcome demonstrates that even in constrained contexts, targeted interventions can deliver significant benefits [21].

Collectively, these findings show that PV + EE integration is not just a developed-world model but a practical, high-impact solution for African institutions, offering locally grounded evidence to support investment and policy reform.

The Enabling Role of Energy Efficiency

Across all three cases, one consistent lesson emerged: energy efficiency (EE) retrofits are the critical enabler for optimising both the technical and economic performance of rooftop PV systems. Passive measures such as shading, ventilation, and insulation substantially lowered thermal loads, while active measures such as LED lighting and zoned HVAC systems reduced everyday electricity demand [8, 9]. Behavioural interventions, though harder to quantify, contributed additional savings [10]. These reductions directly translated into smaller PV capacities, lower upfront costs, and stronger financial returns. In Uganda, efficiency retrofits cut demand so significantly that the required PV capacity was nearly halved, shifting the project from marginal to highly viable [16]. This validates the global "efficiency-first" principle within the Sub-Saharan context [3].

The findings validate the global “efficiency-first” principle within the Sub-Saharan context, where resources are limited and rising demand risks overwhelming supply. Efficiency measures not only enhance the impact of renewables but also deliver co-benefits such as improved comfort, better lighting, and reduced reliance on noisy diesel generators. These tangible improvements help build institutional and user support for further sustainable initiatives.

It can be concluded that any roadmap for scaling rooftop PV in Africa’s institutional buildings must begin with efficiency. Skipping this step risks locking renewables into wasteful systems, undermining their long-term potential.

5.3 Institutional, Regulatory, and Market Readiness

While the technical feasibility and financial case for PV + EE retrofits are strong, their widespread adoption will depend on supportive institutional and policy frameworks. The cases from Uganda, Zambia, and Nigeria reveal differing levels of readiness.

Uganda has drafted net metering regulations, but implementation remains incomplete. As a result, projects like the case study building could theoretically export surplus power but face uncertainty over compensation. Building energy standards are not enforced, meaning efficiency occurs in isolated projects rather than systemically. On the positive side, innovative private-sector models, such as third-party solar providers, are emerging, though they lack scale without stronger policy backing.

Zambia appears closest to building a cohesive ecosystem. It is updating building codes to integrate efficiency, considering net metering, and leveraging renewable energy financing through its REFiT programme. Early initiatives such as the Integrated Energy Service Company (IESCo) model show promise, but policy enforcement and incentives will be crucial to move from pilots to mainstream adoption.

Nigeria, despite its urgent need, lags furthest. Fragmented governance, weak national standards, and the absence of consistent incentives have kept most projects at pilot scale. However, the Electricity Act (2023) could decentralise power sector regulation and empower states to adopt supportive frameworks. Large international investments in solar mini-grids also suggest growing momentum. Beyond regulation, institutional capacity and market trust are critical. Interviews revealed reliance on foreign-trained consultants for retrofits, highlighting the need to train local professionals in integrated design and PV maintenance. Administrators also expressed hesitance toward new financing models without proven examples. Flagship net-zero public buildings could therefore help build awareness and confidence.

In conclusion, aligning technical potential with institutional readiness requires governments to finalise net metering, enforce building codes, and provide early incentives. Institutions should adopt life-cycle costing to justify investments. Only with such alignment can the successes demonstrated in this study be replicated at scale.

Business Model Adaptation and Localisation

The deployment of integrated EE and PV solutions in the case studies was shaped not only by technology but also by the business models enabling implementation. Each country's context favoured a different approach, highlighting the importance of adaptation and localisation.

In Uganda, the third-party solar service or PPA model proved effective. Here, the provider financed, installed, and maintained the PV system, while the institution paid only for electricity consumed. This model suited Uganda's semi-liberalised market and the pressing need to cut diesel costs, especially where conventional loans were inaccessible. Its success, however, hinges on trust and enforceable contracts, as both provider and client face financial risk. With growing track records, this model could expand to more institutions in Uganda and similar contexts.

In Zambia, the integrated ESCO model bundled retrofits, PV, and maintenance under a single contract, offering clients a simple performance-based solution. Savings from efficiency could be leveraged to finance PV, appealing to clients primarily seeking "lower bills and reliable power." Donor involvement, through co-funding or risk guarantees, further reinforced this model. Its localisation reflects the preference for turnkey services in Zambia's institutional sector.

In Nigeria, PPPs or hybrid models are most suitable, given the scale of investment required for large institutions. Government support through partial funding, guarantees, or concession schemes, can reduce risk while the private sector provides expertise. Early examples exist, such as solar installations in federal universities, but scaling requires standardised frameworks and careful attention to risks like currency volatility or policy uncertainty.

Overall, flexibility in financing and ownership models is as crucial as technology. International templates, PPAs, ESCOs, leases—must be tailored to local financial and cultural realities. Governments can support this by establishing clear legal frameworks and standard contracts, while donors and agencies can pilot and share models across borders, creating a knowledge base for scaling.

Broader Implications for the Region (Uganda, Zambia and Nigeria)

The findings from Uganda, Zambia, and Nigeria carry lessons that extend across Sub-Saharan Africa. At their core, they demonstrate that rooftop PV combined with energy efficiency retrofits can serve as a cornerstone of the region's sustainable energy transition, offering benefits that go well beyond the individual buildings studied.

First, the approach enhances **energy resilience**. In contexts where grids are fragile, enabling schools, hospitals, and offices to partially self-supply can keep essential services running during outages. For mission-critical facilities such as hospitals or data centres, this reliability is not optional but vital. By reducing dependence on the grid and diesel generators, institutions gain continuity in their operations while lowering vulnerability to fuel price volatility.

Second, the model delivers **economic benefits**. For institutions, cost savings from reduced electricity bills and generator fuel translate into budget relief, freeing resources for core services like education and healthcare. At a national level, widespread adoption could reduce costly diesel imports and ease pressure on national grids, redistributing scarce supply to underserved areas. The growth of local industries in solar equipment, insulation, and efficient appliances, alongside the training of technicians and engineers, can also create green jobs and stimulate local economies.

Third, PV + EE contributes directly to **climate mitigation**. By lowering demand and replacing diesel with solar, institutions reduce their carbon footprint. If scaled across thousands of public buildings, such interventions could meaningfully advance progress toward national climate targets under the Paris Agreement.

Finally, the strategy aligns with multiple **Sustainable Development Goals** (SDGs). Beyond SDG 7 (Affordable and Clean Energy), the approach supports SDG 3 (Health), SDG 4 (Education), SDG 9 (Industry and Innovation), SDG 11 (Sustainable Cities), and SDG 13 (Climate Action). Reliable power enables better learning environments, healthcare delivery, and productive workplaces, magnifying the social benefits of technical interventions.

Contributions to Research and Practice

This study also makes distinct contributions to scholarship and applied practice. First, it provides empirical validation of the PV + EE model in Africa. Using real data from three different countries, it demonstrates measurable reductions in demand and favourable financial outcomes, moving beyond the largely theoretical or single-building analyses common in the literature. Second, it applies a standardised cross-country methodology. By using consistent simulation tools and financial metrics across cases, the study introduces a level of comparability rarely achieved in African energy studies. This framework can be replicated in other countries to build a cumulative evidence base.

Third, the research offers an integrated analysis of technical and socio-economic factors. By connecting energy savings and financial metrics with regulatory gaps and market conditions, it reflects the real-world complexity of project implementation. For policymakers and practitioners, this holistic view is particularly valuable. Fourth, the study identifies **business models and enabling conditions** suited to local contexts—PPA models in Uganda, ESCO contracts in Zambia, and PPPs in Nigeria. This contextualisation transforms abstract recommendations into actionable insights for developers and governments.

Finally, the study provides a foundation for knowledge sharing and future research. The case studies function as “living labs” that can inform training, policy design, and donor programming. Future work should track post-implementation performance, examine user behaviour, and assess how evolving policies, such as Nigeria’s Electricity Act, affect viability. In summary, the research shows that rooftop PV with energy efficiency is not merely technically feasible but socially and economically transformative. It

offers a replicable model for scaling sustainable energy across Africa, while also advancing academic understanding of decentralised energy systems in the Global South.

Limitations and Future Research

While this study offers important insights, several limitations should be acknowledged, along with opportunities for future research. First, the **generalisability** of the findings is limited. Only three institutional buildings were analysed, and while they were deliberately diverse, they cannot represent the full spectrum of building types, climates, or operational contexts across Sub-Saharan Africa. Results may differ for hospitals, smaller schools, or facilities in very different climates. Broader multi-country studies with larger samples would help refine and validate best practices. Second, the study relied on **assumptions and data gaps** in modelling. Maintenance was assumed to be adequate, PV degradation minimal, and supportive policies (such as net metering) available. In reality, poor maintenance or policy delays could affect performance and returns. Some building data were also estimated where records were incomplete. More empirical datasets from African buildings are needed to improve model calibration and reliability.

Third, the analysis excluded energy storage, even though batteries could significantly enhance resilience and self-sufficiency where net metering is absent. As storage costs decline, future research should assess the techno-economic viability of PV + EE + storage systems for institutional buildings. Fourth, operational and behavioural dynamics were only partially explored. The long-term persistence of occupant behaviour changes, rebound effects, and user engagement need deeper investigation through longitudinal field studies.

Fifth, the financial analysis did not explicitly model currency risks, inflation, or varying financing structures (e.g., debt vs. grants). Future work could apply advanced financial modelling or scenario analysis to reflect these macroeconomic uncertainties. Sixth, the study captured only a policy snapshot up to 2024. The impact of evolving frameworks, such as Nigeria's Electricity Act (2023) or new building code enforcement in Zambia, should be tracked to assess how reforms affect adoption and economics.

Finally, the research focused mainly on technical and financial outcomes, leaving environmental and social impacts underexplored. Life-cycle assessments of emissions, alongside user experience and wellbeing evaluations, would provide a more holistic view of sustainability. This study should be seen as a foundational step. Addressing these gaps will deepen understanding and support the wider adoption of PV + EE retrofits as part of Africa's sustainable energy transition.

5. Conclusion and Recommendations

This study examined the technical, financial, and policy feasibility of integrating rooftop photovoltaic (PV) systems with energy efficiency (EE) retrofits in institutional buildings across Uganda, Zambia, and Nigeria. Through building energy simulations, financial modelling, and policy analysis, we demonstrated that integrated PV + EE solutions are both feasible and highly beneficial in Sub-Saharan African contexts.

Across all three cases, the combined approach proved transformative. Energy demand was reduced by 35–65% through retrofits, which allowed smaller and more affordable PV systems to meet the remaining needs. As a result, each building achieved strong financial outcomes: positive net present values, high internal rates of return, and payback periods well below ten years. The consistency of these results, across a diesel-reliant office in Uganda, a solar-ready office in Zambia, and a retrofitted academic block in Nigeria, underscores the robustness of the PV + EE model.

Technically, the findings show that near net-zero energy operation is achievable in African institutional buildings when efficiency and renewable are pursued together. Even in the challenging Nigerian case, aggressive retrofits paired with PV met almost all annual energy needs. This demonstrates that constraints of climate or infrastructure do not preclude net-zero outcomes if efficiency is prioritised.

Financially, the results dispel the notion that green solutions are too costly for developing countries. By displacing expensive diesel generation and reducing grid reliance, the projects generated high lifetime returns and rapid paybacks, making them attractive if capital can be mobilised. This opens opportunities for financing mechanisms such as green loans, energy service contracts, and concessional funds, since the projects are able to repay themselves.

From a policy perspective, the study highlights the need for enabling frameworks. Regulatory uncertainty, such as incomplete net metering rules or weak building code enforcement, remains a major obstacle. Policymakers should prioritise finalising net metering, strengthening energy codes, and offering financial incentives to de-risk projects. Zambia and Nigeria's recent reforms are encouraging, but more comprehensive action is required to unlock scale.

Equally important is the localisation of *business models*. Uganda's third-party service contracts, Zambia's integrated ESCOs, and Nigeria's PPP approaches illustrate that no single model will suit all contexts. Tailoring financing and ownership structures to local realities is essential for uptake. In conclusion, decentralised PV + EE solutions offer a practical pathway to strengthen energy security, reduce diesel dependence, and advance climate goals in Sub-Saharan Africa. With supportive policy, financing innovation, and scaling of proven models, schools, hospitals, offices, and universities can transition to resilient, affordable, and sustainable energy systems.

Recommendations

To accelerate adoption of rooftop PV systems integrated with energy efficiency (EE) retrofits in Sub-Saharan Africa's institutional buildings, coordinated action from policymakers, financiers, and industry stakeholders is essential. Based on this study's findings, we recommend the following

1. **i. Strengthen Policy Frameworks.** Governments should establish clear net metering or feed-in tariff policies to ensure institutions can export surplus solar power and receive compensation. Updating national building codes to mandate efficiency standards for new construction and major

renovations is equally important, especially in the public sector. Strong enforcement mechanisms must accompany these codes to prevent inefficient designs from locking in future energy waste.

2. **ii. Provide Financial Incentives and Support.** Fiscal incentives such as tax credits, import duty waivers, and accelerated depreciation for PV and EE equipment can reduce costs. Governments should also leverage international climate finance, through mechanisms like the Green Climate Fund to support concessional loans and grants. Local banks can be encouraged, with risk guarantees from multilateral lenders, to create dedicated green loan products and bonds. Such tools will de-risk early projects and stimulate broader market uptake.
3. **iii. Enhance Institutional Coordination and Capacity.** Fragmentation across ministries and agencies undermines progress. Inter-ministerial task forces on sustainable energy in public facilities should be established to ensure coherent strategies. Capacity-building programs are vital to train engineers, architects, and technicians in PV design, auditing, and efficient building operation. Donor agencies can play a role through technical training and exchange programs. Embedding sustainability criteria in public procurement, such as requiring solar readiness and EE assessments in all government projects, would institutionalize best practices.
4. **iv. Encourage Performance-Based Business Models.** Governments should incentivize third-party ownership models such as solar power purchase agreements (PPAs), ESCO contracts, and lease-to-own schemes that reduce upfront costs for institutions. Risk guarantees and standardized contract templates can build trust and lower transaction costs. Piloting these models in flagship institutions (universities, hospitals) would generate demonstrable success stories to encourage replication.
5. **v. Integrate Design and Planning Processes.** Early integration of efficiency and renewables into building design is more cost-effective than retrofitting later. University curricula and professional guidelines should be updated to emphasize passive design principles (orientation, shading, natural ventilation) and structural allowances for PV. Urban planning policies can mandate “solar-ready” and “efficiency-ready” certification for large developments, embedding sustainability as a default.
6. **vi. Invest in O&M and Monitoring.** Long-term project success requires consistent upkeep. Institutions should allocate budgets for PV cleaning, inverter checks, and HVAC servicing, as well as install monitoring systems to track performance. Donor-funded projects could include maintenance training and support for 5–10 years to build local capacity. Awareness programs should continue post-installation to ensure behavioral savings are sustained and rebound effects minimized.
7. **vii. Create Knowledge-Sharing Platforms.** Regional knowledge networks can accelerate adoption by sharing open-access simulation data, cost-benefit analyses, technical guidelines, and case studies. Governments, research institutions, and international partners should collaborate on such platforms. Peer learning—where facilities managers exchange experiences across countries—can reduce duplication of effort and speed up implementation.

Pursuing these actions can create a self-reinforcing cycle: policies and incentives drive projects; successful projects build local expertise and lower costs; declining costs then attract further investment and justify stronger policy action. Institutional buildings, especially in education, healthcare, and government, are ideal starting points. Their visibility and leadership potential can showcase the benefits

of sustainable energy, build trust, and stimulate wider market growth. With technologies mature and needs urgent, coordinated efforts can deliver cleaner, more resilient, and cost-effective energy systems across the region.

Ethical Considerations:

This research was conducted in accordance with established ethical standards for data collection, stakeholder engagement, and reporting.

Informed Consent and Confidentiality. For the qualitative component, all interviewees, including facility managers, regulatory officials, and solar developers, were fully briefed on the study's objectives and how their contributions would be used. Participation was voluntary, and informed consent (written or verbal) was obtained before interviews. To protect privacy, no personal names or organisational identifiers are disclosed. Responses are presented in aggregate or anonymous form, ensuring participants could share insights freely without fear of attribution.

Institutional Approvals. Each case study stemmed from postgraduate research projects at accredited universities, with ethical clearance obtained through relevant institutional review processes. Site visits, meter readings, and interviews were carried out only after securing permissions from building owners and local authorities.

Data Handling and Security. Sensitive materials including energy bills, diesel use logs, and building design documents were treated confidentially. Data were securely stored on password-protected devices or university servers and accessed only by the research team. In reporting, potentially sensitive figures were anonymised or expressed as ranges to avoid disclosing competitive or proprietary details.

Integrity and Accuracy. Findings are presented truthfully, with clear acknowledgment of assumptions, limitations, and modeled projections. Where team members had prior involvement in projects, data were independently verified to maintain objectivity. No funding body influenced results.

Social and Environmental Responsibility. Given the focus on sustainability, the study is ethically committed to advancing societal benefit. Findings will be shared not only with academic audiences but also with institutions and ministries in the studied countries to inform practice and policy.

Contributions

This study advances knowledge and practice in sustainable energy deployment within the built environment, with particular relevance to developing regions.

Novel Integration of Concepts. By combining energy efficiency retrofits with rooftop PV deployment in a Sub-Saharan African context, this research provides rare empirical evidence that demand reduction and local renewable generation can work effectively together. This fills a gap in the literature and offers a replicable model for tropical and subtropical settings.

Comparative Regional Perspective. Few studies in Africa adopt a cross-country lens. By examining Uganda, Zambia, and Nigeria, this work highlights how outcomes vary with local climate, infrastructure, and regulatory environments, demonstrating that “context matters” and broadening the applicability of results.

Methodological Framework. A practical framework integrating energy simulation, financial analysis, and policy review is presented. This holistic approach can be adopted by researchers, policymakers, or development agencies for feasibility studies and pilot programs.

Policy and Business Model Insights. The study identifies enabling policies (such as net metering and efficiency standards) and effective business models (third-party PPAs, ESCOs, PPPs), offering actionable guidance for governments, donors, and private actors seeking to scale projects.

Educational and Capacity-Building Value. The breadth of analysis – spanning technical, financial, and institutional dimensions – makes this work a useful teaching resource for engineering, architecture, and policy courses, as well as for practitioner training.

Catalyst for Future Research. By acknowledging limitations and proposing directions – such as post-implementation monitoring and the role of storage – the study stimulates new lines of inquiry and innovation.

Decision-Making Support. Importantly, the findings empower institutional leaders and energy managers with locally grounded evidence to justify investments, secure funding, or advocate for supportive policies.

In summary, this study contributes empirically validated knowledge, practical guidance, and a framework for future research, supporting greener, more resilient, and efficient buildings across the Global South.

Declarations

Conflict of Interest:

The authors declares no conflicts of interest that could have influenced the conduct, analysis, or reporting of this study. However, the article is not in consideration elsewhere for publication or has ever being published.

Ethics Approval:

Ethical principles of transparency, integrity, and responsible scholarship were strictly observed. Therefore, ethics approval was not required.

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Author Contribution

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Data Availability:

Data supporting the findings of this study (on line) should be available with or without the request of the authors.

References

1. Eberhard, A., Gratwick, K., & Morella, E. (2002). The evolution of the power sector in Sub-Saharan Africa. *Energy Policy*, *161*. 10.1016/j.enpol.2021.112761)
2. Raji, B., & Luthander, R. (2021). Towards cost-optimal net-zero buildings: A case for EE–PV synergy in temperate climates. *Renewable Energy*, *164*, 1245–1255. 10.1016/j.renene.2020.10.014)
3. Wang, Q., Zhang, F., & Jin, J. (2022). Rooftop PV and energy efficiency synergy: Lessons from the EU and China. *Renewable and Sustainable Energy Reviews*, *158*, 112074. 10.1016/j.rser.2021.112074)
4. Masson, G., Kaizuka, I., & Taylor, M. (2021). *Trends in Photovoltaic Applications 2021*. International Energy Agency – PVPS. See https://iea-pvps.org
5. Komendantova, N., & Patt, A. (2020). Designing policies to overcome barriers for renewable energy deployment: The case of North Africa. *Renewable and Sustainable Energy Reviews*, *114*, 109318. 10.1016/j.rser.2019.109318)
6. Zhao, X., Xu, T., & Zhang, C. (2020). Life-cycle cost analysis of rooftop PV in tropical developing countries. *Energy*, *199*, 117486. 10.1016/j.energy.2020.117486)
7. Abanda, F. H., & Byers, L. (2016). An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM. *Energy*, *97*, 517–527. 10.1016/j.energy.2015.12.135)
8. Akuffo, I., Ameyaw, B., & Arthur, B. (2022). Passive design strategies for thermal comfort in institutional buildings in Ghana. *Energy Reports*, *8*, 1904–1917. 10.1016/j.egyr.2022.02.011)
9. Onyeka, E. M., Obinna, N. O., & Ibe, C. O. (2021). Passive solar design as a strategy for sustainable school buildings in Nigeria. *Buildings*, *11*(6), 223. 10.3390/buildings11060223)
10. Mensah, S. A., Anang, K. A., & Djan, A. A. (2022). Energy efficiency retrofits and their impact on building energy use: Case studies from West Africa. *Journal of Building Engineering*, *45*, 103599.

10.1016/j.jobe.2021.103599)

11. Agyekum, E. B., Obaid, A. A., & Shahzad, M. K. (2021). The role of solar energy in reducing energy poverty in Sub-Saharan Africa. *Sustainable Energy Technologies and Assessments*, *43*, 100989. 10.1016/j.seta.2021.100989)
12. Twaha, S., Murphy, J. T., & Murphy, S. (2016). Renewable energy technologies in Uganda: The potential for solar PV in commercial buildings. *Renewable and Sustainable Energy Reviews*, *57*, 786–797. 10.1016/j.rser.2015.12.197)
13. Ibrahim, M. B., Olatunji, S. O., & Adeyanju, G. C. (2023). A review of Nigeria's renewable energy policy and potential for solar PV deployment. *Renewable and Sustainable Energy Reviews*, *177*, 113–182. 10.1016/j.rser.2023.113182
14. International Renewable Energy Agency (IRENA) (2023). *Renewable Capacity Statistics 2023*. See https://www.irena.org/publications/2023/March/Renewable-Capacity-Statistics-
15. Adepoju, O. A., Akinyele, D. O., & Jimoh, A. A. (2022). Barriers and enablers to renewable energy penetration in Sub-Saharan Africa: A review. *Renewable Energy Focus*, *42*, 37–53. 10.1016/j.ref.2022.01.004)
16. Migisha, C. (2018). *Opportunities and Challenges for Distributed Generation with Rooftop PV in Uganda: A Case Study of Crusader House, Kampala*. Master's thesis, University of the Witwatersrand.
17. Nganga, S. K., Wekesa, D. W., & Muriithi, C. M. (2022). Business models for scaling distributed solar PV in Sub-Saharan Africa. *Energy Reports*, *8*, 1889–1902. 10.1016/j.egyr.2022.02.010
18. Samunete, J. (2018). *Decentralised Electricity Generation through Rooftop Solar PVs in Zambia: A Case Study of the Engineering Institute of Zambia Office Building*. Master's thesis, University of the Witwatersrand.
19. Chigbo, A. E., & Abubakar, I. R. (2023). Energy modelling of retrofitted institutional buildings for PV integration in Nigeria. *Energy Reports*, *9*, 2084–2096. 10.1016/j.egyr.2023.02.142)
20. Mahmoud, M. S., Hassan, R., & Osman, N. S. (2021). *Decentralised solar PV adoption in Africa: Business models and policy frameworks*. Energy Policy 156, (2021). (10.1016/j.enpol.2021.112428).
21. Ipinmoroti, S. A. (2017). Solar Energy for Decentralised Electricity Generation for Commercial Buildings in Nigeria: *A Case Study of the Department of Architecture Building at Kogi State Polytechnic*. Master's thesis, University of the Witwatersrand.
22. International Energy Agency (IEA) *Africa Energy Outlook 2023*. See https://www.iea.org/reports/africa-energy-outlook-2023
23. Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., & D'haeseleer, W. (2005). Distributed generation: Definition, benefits and issues. *Energy Policy*, *33*(6), 787–798. 10.1016/j.enpol.2003.10.004)