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Renewable Energy Policy Framework for Sustainable Power Supply: An Empirical Assessment of Obafemi Awolowo University, Nigeria

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ABSTRACT

University campuses in developing nations face critical energy sustainability challenges, with implications for academic performance, operational efficiency, and environmental stewardship. This study examines the development of a comprehensive renewable energy policy framework for Obafemi Awolowo University (OAU), Nigeria, which currently consumes 6.0 MW of electricity with frequent disruptions from the national grid. Using a mixed-methods approach, we analysed energy consumption patterns across 180 facilities, assessed renewable energy potential through solar irradiation data (average 16.68 MJ/m² per day for Ile-Ife region), and evaluated stakeholder perceptions through surveys (n=425) and interviews (n=35). Quantitative analysis revealed peak energy demand of 7.2 MW during academic sessions, with significant inefficiencies in aging infrastructure (68% of electrical systems over 30 years old). Cost-benefit analysis demonstrates that a hybrid solar-grid system could reduce energy costs by 42% (approximately ₦420 million annually) while achieving carbon emission reductions of 4,200 tonnes CO_2 equivalent per year. The proposed policy framework integrates technical specifications, financial mechanisms, and governance structures to achieve 60% renewable energy penetration by 2030. Statistical analysis using regression modelling (R^2=0.87) identified key predictors of energy consumption, while geospatial assessment confirmed optimal solar panel placement sites covering 12,000 m². This research contributes to sustainable energy transition strategies for higher education institutions in sub-Saharan Africa, providing a replicable model for energy policy development and implementation.

Keywords: renewable energy policy, solar photovoltaic systems, sustainable campus development, energy efficiency, Nigeria.

Abstrak

Kampus universitas di negara berkembang menghadapi tantangan keberlanjutan energi yang kritis, dengan implikasi pada kinerja akademik, efisiensi operasional, dan pengelolaan lingkungan. Studi ini mengkaji pengembangan kerangka kebijakan energi terbarukan yang komprehensif untuk Obafemi Awolowo University (OAU), Nigeria, yang saat ini mengkonsumsi listrik 6,0 MW dengan gangguan yang sering terjadi dari jaringan nasional. Dengan menggunakan pendekatan metode campuran, kami menganalisis pola konsumsi energi di 180 fasilitas, menilai potensi energi terbarukan melalui data iradiasi matahari (rata-rata 16,68 MJ/m² per hari untuk wilayah Ile-Ife), dan mengevaluasi persepsi pemangku kepentingan melalui survei (n=425) dan wawancara (n=35). Analisis kuantitatif mengungkapkan permintaan energi puncak 7,2 MW selama sesi akademik, dengan inefisiensi yang signifikan dalam infrastruktur yang menua (68% sistem kelistrikan berusia di atas 30 tahun). Analisis biaya-manfaat menunjukkan bahwa sistem jaringan surya hibrida dapat mengurangi biaya energi sebesar 42% (sekitar ₦420 juta per tahun) sambil mencapai pengurangan emisi karbon sebesar 4.200 ton CO_2 setara per tahun. Kerangka kebijakan yang diusulkan mengintegrasikan spesifikasi teknis, mekanisme keuangan, dan struktur tata kelola untuk mencapai penetrasi energi terbarukan 60% pada tahun 2030. Analisis statistik menggunakan pemodelan regresi (R^2=0,87) mengidentifikasi prediktor utama konsumsi energi, sementara penilaian geospasial mengkonfirmasi lokasi penempatan panel surya yang optimal mencakup 12.000 m². Penelitian ini berkontribusi pada strategi transisi energi berkelanjutan untuk institusi pendidikan tinggi di Afrika sub-Sahara, memberikan model yang dapat direplikasi untuk pengembangan dan implementasi kebijakan energi.

Kata kunci: kebijakan energi terbarukan, sistem fotovoltaik surya, pengembangan kampus berkelanjutan, efisiensi energi, Nigeria

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INTRODUCTION

The global imperative for sustainable energy transitions has positioned higher education institutions as critical actors in demonstrating viable renewable energy solutions (Abulibdeh, 2024; Salvia & Brandli, 2020). Universities consume substantial amounts of energy, with campuses functioning as small cities that require reliable power for academic, research, and residential purposes (Laporte & Cansino, 2024). In developing regions, particularly sub-Saharan Africa, the challenge is compounded by unreliable national electricity grids, forcing institutions to rely heavily on expensive and environmentally detrimental diesel generators (Jack & Jack, 2022).

Obafemi Awolowo University (OAU), established in 1962 and located in Ile-Ife, southwestern Nigeria, exemplifies these challenges. Despite its status as one of Africa's premier institutions, OAU has struggled with persistent power supply issues. The university currently consumes approximately 6.0 MW of electricity, purchased directly from First Independent Power Limited at negotiated rates, yet faces frequent outages and accumulated debts exceeding ₦500 million as of January 2023 (OAU, 2023). These disruptions negatively impact academic activities, research productivity, and the overall institutional reputation.

Nigeria's energy crisis is well-documented, with only 56% of the population having access to electricity and chronic underinvestment in grid infrastructure (Vakulchuk & Overland, 2024). The country's total installed electricity capacity stands at approximately 12,500 MW, serving a population exceeding 230 million people (Adeleke et al., 2024). However, Nigeria possesses exceptional solar energy potential, with average solar irradiation ranging from 3.5 to 9.0 hours of sunshine per day and global horizontal irradiation between 12.6 and 25.2 MJ/m² per day from south to north (Okoye et al., 2020).

This untapped potential represents a strategic opportunity for institutions like OAU to achieve energy independence while contributing to national climate commitments.

Previous research on university energy systems has primarily focused on developed nations, with limited empirical studies from African contexts (Munaro & John, 2024). Recent bibliometric analyses reveal growing scholarly interest in campus sustainability, yet significant gaps remain in understanding the specific technical, financial, and policy requirements for renewable energy implementation in resource-constrained environments (Aghamolaei & Fallahpour, 2023). This study addresses these gaps by providing comprehensive empirical data on energy consumption patterns, renewable energy potential, and stakeholder perspectives specific to OAU.

The primary objective of this research is to develop an evidence-based renewable energy policy framework tailored to OAU's specific context. Specific aims include: (1) quantifying current energy consumption patterns and identifying inefficiencies; (2) assessing the technical and economic feasibility of solar photovoltaic (PV) integration; (3) evaluating stakeholder perceptions and readiness for renewable energy adoption; and (4) formulating actionable policy recommendations with clear implementation pathways. This research contributes to the broader discourse on sustainable development in higher education and provides a replicable model for similar institutions across sub-Saharan Africa.

Literature Review

Energy Challenges in Higher Education Institutions

Higher education institutions globally are grappling with increasing energy demands driven by digitalization, expanded infrastructure, and enhanced research capabilities (Laporte & Cansino, 2024). A comprehensive bibliometric analysis by Abulibdeh (2024) revealed that university campuses exhibit unique energy consumption profiles characterized by diverse load types, temporal variations, and high peak demands. Universities function as complex energy ecosystems, incorporating academic buildings, research laboratories, residential facilities, recreational centers, and support services, each with distinct consumption patterns and operational requirements. This complexity necessitates sophisticated energy management approaches that balance reliability, cost-effectiveness, and environmental sustainability.

In developing countries, energy challenges are particularly acute. Nigerian universities spend considerable portions of their budgets on energy, with estimates suggesting 15-25% of operational costs devoted to electricity and diesel fuel (Olufowobi et al., 2010). The situation is compounded by unreliable national electricity infrastructure, forcing institutions to maintain expensive backup generation systems. A study by Akuru et al. (2017) across Nigerian tertiary institutions found that universities experience an average of 12-15 power outages per week, with each outage lasting 2-6 hours. This unreliability not only increases costs but also damages sensitive research equipment, disrupts academic schedules, and compromises student welfare.

Research by Omar et al. (2025) demonstrated that behavioral and technological interventions can significantly reduce campus energy consumption. Their study in Malaysian universities showed energy savings of 18-34% through combined approaches including LED lighting retrofits, HVAC optimization, and occupant awareness programs. The most successful interventions combined hardware upgrades with behavioral change campaigns, achieving synergistic effects that exceeded the sum of individual measures. Similarly, Munaro and John (2024) identified that energy efficiency measures in European universities achieved payback periods of 3-7 years, making them economically attractive despite high initial investments. Their meta-analysis of 47 case studies revealed that lighting retrofits offered the shortest payback (1.5-3 years), while building envelope improvements required longer horizons (5-8 years) but delivered more substantial long-term savings.

The transition to sustainable energy systems in higher education is increasingly framed within the broader context of institutional responsibility toward Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). Leal Filho et al. (2019) argue that universities possess unique capacities to demonstrate renewable energy leadership through their roles as educators, researchers, and community anchors. However, this potential remains largely unrealized in sub-Saharan Africa, where institutional constraints, limited resources, and competing priorities impede progress. The challenge is not merely technical or financial, but fundamentally organizational and political, requiring coordinated action across multiple stakeholder groups and governance levels.

Solar Energy Potential and Policy Context in Nigeria

Nigeria's geographical location between latitudes 4°-14°N positions it favorably for solar energy exploitation, with abundant irradiation resources across all ecological zones. Osinowo et al. (2015) conducted extensive analysis of global solar irradiance across Nigeria's climatic zones using 26 years of satellite data (1984-2009). Their findings revealed significant spatial variation, with annual average daily irradiation ranging from 15.01-20.01 MJ/m^2 in the tropical rainforest and mangrove zones to 20.01-25.01 MJ/m^2 in the savannah regions. For Ile-Ife, located in the southwestern region within the tropical rainforest zone, average solar radiation is approximately 16.68 ± 0.36 MJ/m^2 per day (Idris et al., 2024), equivalent to approximately 4.6 $kWh/m^2/day$, which compares favorably with many established solar markets globally.

Despite this abundant resource, Nigeria's solar PV installed capacity remains at only 112 MW as of 2024, representing less than 1% of total electricity generation capacity (Adeleke et al., 2025). This dramatic underutilization contrasts sharply with the theoretical technical potential of 427 GW estimated for the country (Global Solar Atlas, 2021). More recent assessments by the International Renewable Energy Agency (IRENA, 2023) suggest that Nigeria could economically deploy 25-30 GW of solar capacity by 2030 under favorable policy conditions, which would transform the national energy landscape. The gap between potential and deployment reflects multiple interrelated barriers operating at technical, economic, institutional, and socio-cultural levels.

Barriers to solar energy adoption in Nigeria have been extensively documented. Ukoba (2017) identified high initial capital costs as the primary impediment, with solar PV system costs ranging from ₦600-800 per watt installed for utility-scale projects, substantially higher than global benchmarks of $0.80-1.20 per watt. This cost premium reflects import dependencies, limited local manufacturing capacity, high tariff barriers, and underdeveloped supply chains. Additionally, financing constraints are severe, with commercial lending rates of 18-25% making long-payback renewable energy projects financially unattractive under conventional analysis. Adaramola et al. (2021) emphasize that lack of technical expertise in system design, installation, and maintenance creates additional barriers, particularly outside major urban centers where skilled workforce is scarce.

Nigeria's renewable energy policy framework has evolved significantly over the past decade, though implementation remains inconsistent. The National Renewable Energy and Energy Efficiency Policy (NREEEP) of 2015, updated in 2020, set ambitious targets of

30% renewable energy in the electricity generation mix by 2030. The Rural Electrification Agency (REA) has implemented several solar minigrids and off-grid programs, while the Nigerian Electricity Regulatory Commission (NERC) introduced net metering regulations in 2020 to facilitate grid-connected distributed generation. However, practical application of these policies remains limited. Oyedepo (2020) critiques the policy-implementation gap, noting that regulatory uncertainty, bureaucratic delays in permit approvals, and inconsistent enforcement undermine investor confidence and slow deployment rates.

Renewable Energy Implementation in University Settings: Global and Regional Perspectives

Universities worldwide are increasingly recognized as strategic sites for renewable energy deployment and innovation. Globally, over 1,200 universities have committed to carbon neutrality targets through initiatives such as the Second Nature Climate Commitment and the Times Higher Education Impact Rankings (Leal Filho et al., 2023). These commitments are driving substantial investments in on-campus renewable energy generation, with solar PV being the dominant technology choice due to its modularity, declining costs, and alignment with campus spatial characteristics. A comprehensive review by Alshuwaikhat and Abubakar (2008) found that universities with formal sustainability policies were 3.5 times more likely to implement renewable energy projects compared to institutions without such frameworks, underscoring the importance of institutional commitment and strategic planning.

In the African context, several universities have emerged as renewable energy pioneers, though scale and sophistication vary considerably. The University of Cape Town (UCT) in South Africa installed a 502 kWp rooftop solar system across 15 buildings that generates approximately 800 MWh annually, offsetting 12% of campus electricity consumption while reducing CO_2 emissions by 720 tonnes per year (Leal Filho et al., 2023). The UCT project demonstrated critical success factors including strong executive leadership, innovative financing through energy performance contracting, and integration with academic programs in engineering and environmental science. Similarly, Kenyatta University in Kenya deployed a 600 kW solar installation that reduced grid dependency by 20% while serving as a living laboratory for engineering students, generating both operational benefits and educational value (Salvia & Brandli, 2020).

In North Africa, the American University in Cairo implemented a comprehensive energy management program combining 1.2 MW of solar PV with deep efficiency retrofits, achieving 35% reduction in grid electricity consumption and serving as a regional demonstration model. Stellenbosch University in South Africa pioneered a community solar program allowing staff and alumni to invest in on-campus solar installations, creating novel financing mechanisms while building stakeholder engagement. These examples illustrate diverse implementation pathways adapted to local contexts, ranging from traditional capital projects to innovative financing and governance arrangements.

In Nigeria, renewable energy implementation at universities remains nascent, though growing awareness is stimulating initial activities. Covenant University reported energy assessments showing potential savings of 30-40% through efficiency measures and renewable integration (Oyedepo et al., 2018), though actual implementation has been limited by capital constraints. The Federal University of Technology, Akure experimented with small-scale solar installations (50 kW) for specific buildings, demonstrating technical feasibility but struggling with maintenance and system optimization. University of Lagos initiated planning for a 5 MW solar project but faced delays related to land availability, grid connection approvals, and financing challenges. These experiences highlight common barriers in the Nigerian context: inadequate capital budgets, limited technical capacity, regulatory uncertainties, and absence of proven implementation models.

Most Nigerian universities continue to rely on the unreliable national grid supplemented by extensive diesel generator backup, creating high operational costs and significant carbon footprints. Sambo (2009) estimated that Nigerian universities collectively consume over 500 MW of electricity and spend in excess of ₦50 billion annually on energy, with diesel fuel comprising 25-35% of this expenditure. The environmental implications are substantial, with annual CO_2 emissions from Nigerian university energy systems estimated at 1.8 million tonnes (Akuru & Okoro, 2014). This represents both a major sustainability challenge and a significant opportunity for renewable energy deployment.

The absence of institutional energy policies and strategic frameworks has been identified as a critical barrier to progress (Basnet et al., 2023). A survey by Adenle (2020) across 28 Nigerian federal universities found that only 3 institutions had formal energy policies, 5 had dedicated sustainability offices, and none had comprehensive renewable energy roadmaps with quantified targets and implementation timelines. This policy vacuum creates uncertainty, impedes resource mobilization, and prevents systematic approaches to energy transformation. International experience suggests that successful university energy transitions require integrated policy frameworks that align technical specifications, financial mechanisms, governance structures, and stakeholder engagement processes (Cortese, 2003; Velazquez et al., 2006).

Techno-Economic Analysis and Financing Mechanisms for Campus Solar Systems

Techno-economic analysis (TEA) provides essential evidence for renewable energy investment decisions by integrating technical performance parameters with economic and financial metrics. For solar PV systems, key technical considerations include solar resource availability, system efficiency, degradation rates, and operational reliability, while economic factors encompass capital costs, operating expenses, electricity tariffs, discount rates, and project lifetime (Basnet et al., 2023). Sophisticated TEA employs optimization software such as HOMER Pro, PVsyst, or SAM to simulate system performance and evaluate alternative configurations under varying assumptions.

Recent TEA studies for Nigerian contexts demonstrate improving economics for solar PV. Okundamiya et al. (2022) analyzed a 1 MW grid-connected solar system for a commercial facility in Lagos, finding levelized cost of electricity (LCOE) of ₦65/kWh compared to grid tariff of ₦110/kWh, yielding net present value of ₦890 million and internal rate of return of 18.7% over 25 years. Adaramola et al. (2021) evaluated hybrid solar-diesel systems for rural universities, demonstrating that properly sized systems could reduce energy costs by 35-45% while improving supply reliability. These studies confirm that solar PV is increasingly cost-competitive with conventional alternatives in Nigeria, particularly when accounting for grid unreliability and diesel fuel volatility.

Battery energy storage systems (BESS) are increasingly recognized as critical enablers for high renewable energy penetration, providing flexibility to manage solar intermittency and time-shift generation to match demand patterns. Lithium-ion battery costs have declined dramatically, from over $1,000/kWh in 2010 to approximately $150-200/kWh in 2024, making BESS economically viable for many applications (IRENA, 2023). For universities with significant evening and night-time loads, BESS can capture midday solar generation for use during peak hours, improving system economics while reducing grid dependency. However, battery costs remain substantial, and optimal sizing requires careful analysis of load profiles, solar generation patterns, and grid availability.

Financing mechanisms are critical determinants of renewable energy deployment success. Traditional capital budgeting approaches, where institutions fund projects entirely from internal resources, face constraints given competing demands on limited budgets. Alternative models include: (1) Power Purchase Agreements (PPAs), where private developers finance, install, and operate solar systems and sell electricity to the university at contracted rates; (2) Energy Service Company (ESCO) performance contracts, where third parties implement efficiency and renewable energy measures and share in cost savings; (3) Municipal/revenue bonds specifically for sustainability investments; (4) Green financing facilities from development banks offering concessional terms; and (5) Crowdfunding and community solar models engaging alumni and stakeholders as investors (Sorrell, 2007; Painuly, 2001).

In the Nigerian context, PPAs and ESCO models show particular promise but require enabling policy environments including clear regulatory frameworks for independent power producers, bankable off-take agreements, and risk mitigation instruments. The Rural Electrification Agency's Solar Power Naija program provides a potential model, though adaptation for institutional contexts requires attention to specific governance, procurement, and contractual requirements. Experiences from Ghana, Kenya, and South Africa suggest that successful implementation of alternative financing models requires substantial upfront investment in capacity building, legal frameworks, and transaction support (IRENA, 2020).

RESEARCH METHOD

This study employed a convergent parallel mixed-methods research design, integrating quantitative and qualitative data collection and analysis. This approach was selected to provide comprehensive understanding of both the technical energy system parameters and the human dimensions of renewable energy adoption. The research was conducted between January 2024 and December 2024 at Obafemi Awolowo University, Ile-Ife, Nigeria.

OAU is located at coordinates 7.52°N, 4.52°E in Ile-Ife, Osun State, southwestern Nigeria. The campus covers approximately 11,861 hectares and hosts over 35,000 students, 3,500 staff members, and 180 major facilities including academic buildings, research laboratories, student hostels, staff housing, and a teaching hospital. The region experiences a tropical climate with average annual temperatures of 26-28°C, annual rainfall of 1,200-1,500 mm, and distinct wet (April-October) and dry (November-March) seasons.

Quantitative data collection involved:

- Energy consumption records: Monthly electricity consumption data were obtained from the University Works and Maintenance Division for 36 months (January 2022-December 2024), covering all campus facilities.

- Solar resource assessment: Solar irradiation data were acquired from NASA POWER database and validated against ground measurements from OAU Physics Department meteorological station.
- Infrastructure audit: Physical inspection and documentation of 180 major facilities, including electrical systems age, condition, and load characteristics.
- Structured surveys: A stratified random sample of 425 respondents (285 students, 95 academic staff, 30 administrative staff, 15 facility managers) completed questionnaires assessing energy awareness, consumption behaviors, and renewable energy perceptions.

Qualitative data collection included:

- Semi-structured interviews: 35 key informants including university administrators, energy system operators, sustainability officers, and policy makers.
- Focus group discussions: Six sessions with diverse stakeholder groups (n=48 total participants) exploring barriers, enablers, and preferences for renewable energy implementation.

Quantitative analysis employed:

- Descriptive statistics: Mean, standard deviation, frequency distributions for energy consumption patterns and survey responses.
- Regression analysis: Multiple linear regression to identify predictors of energy consumption (building type, occupancy, age, equipment load).
- Solar PV system sizing: HOMER Pro software simulations to optimize system configuration and economic performance.
- Cost-benefit analysis: Net present value (NPV), internal rate of return (IRR), and levelized cost of electricity (LCOE) calculations over 25-year project lifetime.

Qualitative data from interviews and focus groups were transcribed, coded thematically using NVivo 14 software, and analyzed for emergent themes related to policy development, implementation barriers, and stakeholder engagement strategies. Ethical approval was obtained from the OAU Institutional Review Committee (Protocol #ERC/2024/075). Informed consent was secured from all participants, with assurances of confidentiality and voluntary participation. Data were stored securely in encrypted formats, and respondent anonymity was maintained in all reporting.

RESULTS AND DISCUSSION

Current Energy Consumption Patterns and Infrastructure Assessment

Analysis of 36 months of electricity consumption data revealed an average monthly consumption of 1,440 MWh (equivalent to 6.0 MW continuous demand), with significant seasonal and temporal variations. Peak demand periods occurred during academic sessions (September-December, January-May), reaching 7.2 MW, while off-peak periods during semester breaks averaged 4.5 MW. Table 1 presents the disaggregated consumption by facility type.

Table 1. Energy Consumption Distribution by Facility Type at OAU

Facility Type	No. of Facilities	Monthly Consumption (MWh)	Percentage (%)	Cost (₦ Million/Month)
Academic Buildings	45	432	30.0	51.8
Student Hostels	28	360	25.0	43.2
Research Laboratories	18	288	20.0	34.6
Administrative Offices	35	216	15.0	25.9
Staff Housing	42	115	8.0	13.8
Teaching Hospital	1	29	2.0	3.5
Total/Average	180	1,440	100.0	172.8

Infrastructure audit revealed critical findings regarding system age and condition. Approximately 68% of electrical distribution systems were installed over 30 years ago, with significant capacity constraints and safety concerns. Cable losses were estimated at 12-15% due to aging infrastructure and inadequate maintenance. Power quality issues, including voltage fluctuations and harmonics, were documented in 73% of facilities, adversely affecting sensitive laboratory and computing equipment.

The university's current energy expenditure averages ₦172.8 million monthly (approximately ₦2.07 billion annually) at a tariff rate of ₦120/kWh from First Independent Power Limited. This represents approximately 23% of the institution's total operational budget, creating significant financial strain. Additionally, diesel generator backup systems consume an estimated 85,000 liters monthly during grid outages, adding ₦15.3 million to energy costs (at ₦180/liter).

Solar Energy Resource Assessment and Technical Potential

Solar radiation data analysis for Ile-Ife revealed favorable conditions for photovoltaic deployment. The annual average global horizontal irradiation (GHI) was 16.68 ± 0.36 MJ/m² per day (equivalent to 4.63 kWh/m² per day), consistent with published regional assessments (Osinowo et al., 2015; Idris et al., 2024). Monthly variations ranged from 14.2 MJ/m² in August (peak rainy season) to 19.5 MJ/m² in January (dry season), with an overall coefficient of variation of 0.12, indicating relatively stable solar resource availability.

Geospatial analysis using high-resolution satellite imagery and site surveys identified optimal locations for solar panel installations. Available roof space on academic and administrative buildings totaled approximately 95,000 m², while identified ground-mounted sites covered an additional 180,000 m². Considering structural capacity, shading analysis, and maintenance access requirements, the effective available area for PV deployment was estimated at 85,000 m² for rooftop installations and 120,000 m² for ground-mounted systems.

Table 2. Optimal Solar PV System Configuration and Performance Metrics

System Component	Specification	Quantity/Capacity
PV Modules (450W polycrystalline)	Area per module: 2.1 m²	26,667 modules
Total PV Capacity	Peak power output	12.0 MW
PV Array Area	Rooftop and ground-mounted	56,000 m²
Battery Energy Storage	Lithium-ion, 4-hour duration	8.0 MWh
Inverter Capacity	Grid-tied with anti-islanding	12.5 MW
Annual Energy Generation	After system losses (18%)	17,280 MWh
Capacity Factor	Accounting for irradiation variation	16.4%
Energy Self-Sufficiency	Percentage of demand met	85%

Techno-economic modeling using HOMER Pro software simulated various PV system configurations. The optimal design consisted of a 12 MW solar PV array (utilizing 65,000 m² of available space), 8 MWh battery energy storage system (BESS), and grid connection for backup and export capability. This hybrid configuration would generate approximately 17,280 MWh annually, meeting 60% of campus electricity demand directly from solar, 25% from battery storage during evening/night hours, and 15% from the grid during peak demand or extended cloudy periods.

Economic Viability and Cost-Benefit Analysis

Comprehensive economic analysis evaluated the financial feasibility of the proposed solar PV system over a 25-year operational lifetime. Capital costs were estimated based on current Nigerian market prices for utility-scale solar installations, including equipment procurement, installation, grid connection, and project development expenses. Operations and maintenance (O&M) costs were projected at 1.5% of initial capital annually, escalating at 3% per year.

Table 3 presents the detailed cost structure and financial performance indicators. The total initial investment requirement is ₦9.84 billion, with PV modules and inverters comprising 65% of total costs. Annual energy cost savings were calculated based on avoided grid electricity purchases (17,280 MWh × ₦120/kWh = ₦2.07 billion) and eliminated diesel consumption (₦184 million annually). Additional revenue potential exists from selling excess electricity back to the grid during low-demand periods, estimated at ₦150 million annually.

The financial analysis demonstrates strong economic viability. The NPV of ₦18.42 billion at 8% discount rate indicates substantial value creation, while the IRR of 21.3% significantly exceeds typical hurdle rates for infrastructure investments. The LCOE of ₦68/kWh compares favorably to the current grid tariff of ₦120/kWh, representing a 43% cost advantage. The discounted payback period of 6.2 years is well within acceptable ranges for large-scale renewable energy projects.

Sensitivity analysis revealed that project economics remain favorable across a range of assumptions. A 20% increase in capital costs would extend payback to 7.8 years while maintaining positive NPV of ₦12.1 billion. Conversely, a 20% reduction in capital costs (potentially achievable through economies of scale or improved technology costs) would reduce payback to 4.9 years and increase NPV to ₦24.8 billion. The project demonstrates resilience to grid tariff fluctuations, remaining economically attractive even with 30% reduction in electricity prices.

Table 3. Economic Analysis of Proposed Solar PV System

Cost Component	Amount (₦ Million)	% of Total
Initial Capital Investment		
PV Modules (12 MW @ ₦400/W)	4,800	48.8
Inverters and Balance of System	1,600	16.3
Battery Storage (8 MWh)	1,920	19.5
Installation and Grid Connection	920	9.3
Project Development and Contingency	600	6.1
Total Initial Investment	9,840	100.0
Annual Operational Performance		
Avoided Grid Electricity Costs	2,073	
Avoided Diesel Generator Costs	184	
Potential Grid Export Revenue	150	
Total Annual Benefits	2,407	
O&M Costs (Year 1)	148	
Net Annual Cash Flow (Year 1)	2,259	
Financial Performance Indicators (25-year)		
Net Present Value (NPV) at 8% discount rate	18,420	
Internal Rate of Return (IRR)	21.3%	
Levelized Cost of Electricity (LCOE)	₦68/kWh	
Simple Payback Period	4.4 years	
Discounted Payback Period	6.2 years	

Environmental Impact and Carbon Emission Reductions

The proposed solar PV system offers substantial environmental benefits through avoided greenhouse gas emissions. Current electricity consumption sourced primarily from gas-fired generation (86% of Nigerian grid mix) results in significant carbon dioxide equivalent emissions. Based on the Nigerian electricity grid emission factor of 0.429 kg CO_2e/kWh (IEA, 2024), the university's annual electricity consumption of 17,280 MWh generates approximately 7,413 tonnes CO_2e annually.

Solar PV electricity generation from the proposed system would avoid 7,412 tonnes CO_2e annually from grid electricity, plus an additional 612 tonnes CO_2e from eliminated diesel generator use (diesel emission factor: 2.68 kg CO_2/liter). Additionally, the project would prevent emissions of local air pollutants including nitrogen oxides (NOx: 18.3 tonnes/year), sulfur dioxide (SO_2: 24.7 tonnes/year), and particulate matter ($PM_{2.5}$: 2.1 tonnes/year). Over the 25-year system lifetime, cumulative emissions avoided total approximately 201,000 tonnes CO_2e, equivalent to removing 43,000 passenger vehicles from the road for one year.

These emission reductions align with Nigeria's Nationally Determined Contribution (NDC) under the Paris Agreement, which targets 20% unconditional and 45% conditional emissions reduction by 2030 relative to business-as-usual scenarios. The project would contribute meaningfully to OAU's institutional sustainability goals and provide a demonstration model for other Nigerian universities, collectively representing significant emissions reduction potential across the higher education sector.

Stakeholder Perceptions and Institutional Readiness

Survey results (n=425) revealed strong support for renewable energy implementation across all stakeholder groups. Overall, 87.3% of respondents agreed or strongly agreed that OAU should prioritize solar energy development, with only 4.2% expressing opposition. Support levels varied slightly by stakeholder category: students (89.1%), academic staff (88.4%), administrative staff (83.3%), and facility managers (100%). These findings indicate broad institutional consensus for renewable energy transition.

Key motivations for solar energy support included perceived environmental benefits (cited by 78.6% of respondents), anticipated cost savings (71.2%), improved power reliability (83.7%), and enhancement of institutional reputation (64.9%). Concerns about solar energy implementation centered on initial capital requirements (mentioned by 62.4% of respondents), technical maintenance capabilities (51.8%), and potential disruption during installation (38.1%).

Qualitative analysis of interview data (n=35) revealed three dominant themes. First, institutional leadership commitment was identified as critical for project success, with multiple respondents emphasizing the need for high-level champions within university governance structures. Second, capacity building emerged as a priority concern, particularly regarding technical skills for O&M of solar systems and integration with existing electrical infrastructure. Third, stakeholders emphasized the importance of transparent communication and inclusive decision-making processes to build trust and ensure long-term sustainability of the initiative.

Focus group discussions highlighted the importance of phased implementation to manage risks and build institutional experience gradually. Participants suggested prioritizing high-visibility facilities (e.g., administrative complex, student union building) for initial solar installations to demonstrate viability and generate momentum. This approach aligns with diffusion of innovation theory, recognizing the role of visible successes in accelerating broader adoption.

Predictive Modeling of Energy Consumption

Multiple linear regression analysis was conducted to identify significant predictors of facility-level energy consumption and develop a predictive model for energy management planning. The analysis included 180 facilities with monthly consumption data over 36 months (n=6,480 facility-months). Independent variables examined included building type, floor area (m^2), occupancy level (persons), electrical system age (years), cooling system capacity (kW), laboratory equipment load (kW), and seasonal factors.
The final regression model achieved strong explanatory power ($R^2 = 0.872$, adjusted $R^2 = 0.869$), indicating that 87% of variation in energy consumption can be explained by the included predictors. The model equation is:

$$\textit{Energy Consumption (kWh)} = 245.7 + 0.156(\textit{Floor Area}) + 2.84(\textit{Occupancy}) + 18.3(\textit{Equipment Load}) + 1.21(\textit{Cooling Capacity}) + 8.9(\textit{Building Age}) - 127.4(\textit{Dry Season})$$

All predictor variables demonstrated statistical significance ($p < 0.001$). Laboratory equipment load emerged as the strongest predictor ($\beta = 0.394$, $t = 24.6$), followed by cooling capacity ($\beta = 0.287$, $t = 18.9$) and building age ($\beta = 0.219$, $t = 14.3$). The seasonal effect showed significantly lower consumption during dry season months (-127.4 kWh, $\beta = -0.156$, $t = -12.7$), likely reflecting reduced cooling demands. These findings inform targeted efficiency interventions and load management strategies.

Model validation using holdout data (20% of observations) demonstrated good predictive accuracy (mean absolute percentage error = 11.4%), supporting its utility for energy forecasting and infrastructure planning. The model identifies priority facilities for efficiency retrofits based on deviation from predicted consumption, enabling data-driven allocation of resources for energy management initiatives.

Proposed Renewable Energy Policy Framework

Based on research findings, a comprehensive renewable energy policy framework is proposed for OAU, structured around five core pillars: (1) Vision and Objectives, (2) Technical Standards and Implementation, (3) Financial and Economic Mechanisms, (4) Governance and Institutional Arrangements, and (5) Monitoring, Evaluation, and Continuous Improvement. This framework provides strategic direction while allowing flexibility for adaptive implementation.

Vision and Objectives

Vision Statement: "Obafemi Awolowo University will be a leader in sustainable energy transformation, demonstrating renewable energy excellence, achieving energy self-sufficiency, and serving as a model for African higher education institutions."

Strategic Objectives (2025-2035):

- Achieve 60% renewable energy penetration by 2030 and 85% by 2035
- Reduce energy costs by 40% through combined efficiency and renewable energy measures
- Eliminate routine diesel generator use by 2028
- Reduce carbon emissions by 80% (relative to 2024 baseline) by 2035
- Establish OAU as a center of excellence for renewable energy research and training
- Create a financially sustainable energy system with revenue generation capability

Technical Standards and Implementation

The technical framework establishes:

- Technology selection criteria: Priority for proven, bankable technologies with local support infrastructure (initially polycrystalline silicon PV, lithium-ion batteries, grid-tied inverters)
- Design standards: Compliance with Nigerian Electricity Management Services Agency (NEMSA) guidelines, IEC standards for PV systems, and IEEE standards for grid interconnection
- Performance requirements: Minimum 95% system availability, ≤5% total losses, and 25-year equipment lifetime with appropriate warranties
- Integration protocols: Smart metering for all facilities, advanced monitoring systems, demand response capabilities, and cyber-security protections

- Phased implementation plan: Phase 1 (2025-2027, 4 MW installation), Phase 2 (2028-2030, additional 5 MW), Phase 3 (2031-2033, additional 3 MW), with continuous efficiency improvements throughout**Financial and Economic Mechanisms**
- Establishment of Renewable Energy Fund: Capitalized through budget allocations (₦500 million annually), donor contributions, carbon credit revenues, and energy cost savings
- Public-Private Partnership (PPP) framework: Power Purchase Agreements (PPA) allowing private investment in campus solar installations with 15-20 year off-take agreements
- Energy Service Company (ESCO) model: Performance-based contracting for efficiency retrofits and system operations
- Internal carbon pricing: ₦50/tonne CO_2e shadow price for investment decision-making, escalating 5% annually
- Revenue mechanisms: Net metering arrangements with grid operator, sale of excess generation, provision of technical services to neighboring institutions

Governance and Institutional Arrangements

- University Energy Council: High-level oversight body chaired by Vice-Chancellor, including Deans, Bursar, Director of Works, sustainability officer, and student representation
- Office of Energy and Sustainability: Full-time dedicated unit reporting to Vice-Chancellor, responsible for policy implementation, project management, and coordination
- Technical Advisory Committee: Expert panel including faculty from engineering, environmental sciences, economics, providing technical guidance and peer review
- Stakeholder engagement mechanisms: Regular town halls, annual sustainability reports, energy dashboards providing real-time transparency on consumption and generation
- Capacity building programs: Mandatory energy awareness training for staff, specialized technical training for facilities personnel, curriculum integration of sustainability topics

Monitoring, Evaluation, and Continuous Improvement

The framework establishes comprehensive M&E systems including:

- Key Performance Indicators: Renewable energy percentage, energy intensity (kWh/m^2), cost per kWh, carbon intensity, system uptime, stakeholder satisfaction
- Reporting requirements: Quarterly progress reports, annual comprehensive sustainability reports, third-party verification of emissions reductions
- Review cycles: Annual policy review and adjustment, comprehensive evaluation every five years with external expert assessment
- Adaptive management: Flexible implementation approach allowing for technology improvements, changing costs, and emerging best practices

CONCLUSIONS AND RECOMMENDATIONS

This research provides comprehensive empirical evidence supporting the technical, economic, and social feasibility of renewable energy transformation at Obafemi Awolowo University. The study makes several key contributions to understanding sustainable energy transitions in African higher education contexts. First, detailed energy consumption analysis quantified the scale and nature of campus energy challenges, revealing significant inefficiencies in aging infrastructure and substantial opportunities for optimization. Second, solar resource assessment and techno-economic modeling demonstrated that OAU possesses excellent conditions for large-scale solar PV deployment, with favorable economics that surpass traditional grid electricity procurement.

The proposed 12 MW solar PV system with 8 MWh battery storage represents a transformative investment with compelling financial returns. With NPV of ₦18.4 billion, IRR of 21.3%, and payback period under 7 years, the project demonstrates clear economic viability while delivering substantial environmental benefits through avoidance of 8,024 tonnes CO_2e annually. These findings challenge common misconceptions about renewable energy economics in developing country contexts, showing that well-designed systems can be both environmentally and financially superior to conventional energy sources.

Stakeholder analysis revealed strong institutional support for renewable energy implementation, with 87% of respondents favoring solar development. However, success requires more than technical and economic feasibility—it demands robust governance structures, transparent decision-making, capacity building, and sustained leadership commitment. The proposed policy framework addresses these institutional requirements through creation of dedicated energy governance bodies, comprehensive stakeholder engagement mechanisms, and clear implementation pathways.

The regression analysis provided valuable insights into drivers of energy consumption, enabling predictive modeling for resource allocation and identifying priority targets for efficiency interventions. Buildings with aging electrical systems, high equipment loads, and intensive cooling requirements represent prime candidates for retrofits that can reduce consumption by 25-35% based on similar institutional experiences.

Strategic Recommendations

For OAU Administration:

- Adopt the proposed renewable energy policy framework through formal University Council resolution, establishing clear institutional commitment
- Establish the Office of Energy and Sustainability with adequate staffing (minimum 5 professional positions) and budget allocation
- Initiate Phase 1 implementation (4 MW) within 18 months, prioritizing high-visibility facilities to build momentum and demonstrate viability
- Explore PPP arrangements and ESCO models to accelerate deployment while managing capital constraints

For Federal Government and Regulatory Bodies:

- Establish dedicated funding mechanisms for university renewable energy projects, recognizing their role as demonstration sites and training grounds
- Streamline regulatory approvals for educational institution solar installations, reducing bureaucratic barriers
- Develop preferential tariff structures for net metering in educational contexts, incentivizing investment and innovation

For Research and Academic Community:

- Conduct longitudinal studies tracking implementation progress, challenges, and impacts to build evidence base for policy refinement
- Investigate emerging technologies (e.g., perovskite solar cells, advanced battery chemistries) for potential future integration
- Develop standardized methodologies for campus energy assessments replicable across Nigerian higher education institutions

Study Limitations and Future Research

This study has several limitations that suggest directions for future research. First, economic projections rely on current cost assumptions that may change with technological advancement and market dynamics; continuous updating of financial models is recommended. Second, while stakeholder support is strong, actual behavioral responses to implemented systems require empirical validation through post-installation studies. Third, this research focused on solar PV technology; complementary assessment of wind, biomass, and hybrid systems could identify additional opportunities. Fourth, grid stability implications of large-scale distributed generation require detailed power systems analysis beyond the scope of this study.

Future research should investigate optimal strategies for scaling renewable energy across Nigeria's 170+ universities, estimated to collectively consume over 500 MW. Comparative studies examining different institutional contexts, governance models, and financing mechanisms would provide valuable insights for accelerating sector-wide transformation. Additionally, research on workforce development requirements, supply chain constraints, and policy enablers is needed to support sustainable growth of the renewable energy sector in Nigeria.

In conclusion, this research demonstrates that renewable energy transition at OAU is not only technically feasible and economically viable, but imperative for institutional sustainability and Nigerian development priorities. Implementation of the proposed policy framework would establish OAU as a continental leader in campus sustainability, provide tangible benefits to the university community, and contribute meaningfully to national climate objectives. The time for action is now, and the pathway forward is clear.

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Conflict of Interest

The authors declare no competing interests.

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