



## Integrating Renewable Energy Potential and Life Cycle Costing for Sustainable Energy in Auchi Polytechnic student hostels

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### KEY WORDS

Renewable energy, Solar PV, Life Cycle Costing, Energy sustainability, Reliability analysis, Carbon reduction,

### ABSTRACT

This study evaluates the integration of renewable energy potential and life cycle costing (LCC) for sustainable power generation in Auchi Polytechnic student hostels, Edo State, Nigeria. It addresses the challenge of unreliable grid electricity and the high environmental impact of diesel-based systems by analyzing the technical, economic, and environmental feasibility of renewable alternatives. Field energy audits revealed an average daily consumption of 57.45 kWh, with evening peaks accounting for 37% of total demand. Renewable resource assessments indicated a mean solar irradiance of 5.5 kWh/m<sup>2</sup>/day, confirming strong photovoltaic (PV) potential, while wind and biogas options showed limited viability. Using Life Cycle Cost Analysis (LCCA) over a 20-year horizon, the PV + Battery configuration achieved a total life cycle cost of ₦36.34 million compared to ₦61.88 million for the grid–diesel system, yielding ₦25.54 million in net savings and a 6.7-year payback period. Reliability metrics showed a Loss of Power Supply Probability (LPSP) of 0.37%, RMSE of 1.2 kWh/day, and a 70% CO<sub>2</sub> emission reduction, surpassing performance targets. Stakeholder surveys revealed strong acceptance of solar technology (79.7%) but highlighted barriers such as high initial cost and limited technical capacity. The findings conclude that a solar PV + Battery hybrid system offers a technically reliable, economically viable, and environmentally sustainable solution for institutional energy management, aligning with the United Nations Sustainable Development Goal 7 on affordable and clean energy..

## 1. INTRODUCTION

The construction industry drives socio-economic growth but remains a major consumer of energy and emitter of greenhouse gases. Buildings account for nearly 40% of global energy use and 30% of carbon dioxide (CO<sub>2</sub>) emissions (International Energy Agency [IEA], 2021). In Nigeria, this problem is worsened by poor infrastructure and heavy dependence on diesel generators, which emit about 2.6 kg of CO<sub>2</sub> per liter of fuel consumed (Umar et al., 2020). Such dependence increases costs and environmental degradation, threatening the sustainability of public institutions.

Educational facilities are highly energy-intensive due to continuous electricity needs for lighting, cooling, and digital operations. At Auchi Polytechnic, Edo State, student hostels rely on unstable grid electricity and costly diesel generators (Okafor et al., 2022). To improve reliability and sustainability, renewable energy systems provide an efficient alternative.

Solar photovoltaic (PV) technology is particularly suitable for Nigeria's tropical climate, with average solar radiation between 4.5 and 6.0 kWh/m<sup>2</sup>/day (Ajibade et al., 2021). When properly integrated, PV systems can reduce operational costs, enhance energy security, and support Sustainable Development Goal 7 on affordable and clean energy (United Nations, 2023). However,

renewable adoption remains limited due to high installation costs, inadequate technical capacity, and weak institutional frameworks (Abubakar et al., 2021).

This study evaluates renewable energy potential and life cycle costing for sustainable energy provision in Auchu Polytechnic student hostels. It examines energy demand patterns, assesses renewable resource availability, and applies Life Cycle Cost Analysis (LCCA) to develop a framework for cost-effective and sustainable institutional energy management.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

The study was conducted at Auchu Polytechnic, located in Etsako West Local Government Area of Edo State, Nigeria. The institution lies between latitude 7°04'N and longitude 6°16'E, characterized by a tropical climate with distinct wet and dry seasons. Average daily solar radiation ranges between 4.8 and 5.6 kWh/m<sup>2</sup>, with annual mean temperature values of 27–32 °C (Akinoyemi et al., 2021). The student hostel complex selected for this study consists of multiple residential blocks with an estimated occupancy of over 1,200 students. The hostels are powered mainly by grid electricity and diesel generators, which operate intermittently due to unstable grid supply. This setting provided a representative model for evaluating renewable energy integration in institutional buildings.

### 2.2 Data Collection

Data collection involved three main components:

**2.2.1 Energy Consumption Data:** Daily electricity consumption records and appliance inventories were obtained from hostel management and verified through load measurements using digital energy meters over a four-week monitoring period.

**2.2.2 Renewable Energy Resource Data:** Solar radiation, temperature, and wind speed data were retrieved from the Nigerian Meteorological Agency (NiMET) and validated using *Meteonorm 8.0* and *Climate Consultant* simulation software (Odeyemi et al., 2022).

**2.2.3 Economic and Cost Data:** Capital, operational, and maintenance costs for photovoltaic (PV) systems, inverters, and storage batteries were sourced from current market prices and relevant literature (Ogunmodede et al., 2023).

### 2.3 Analytical Methods

#### 2.3.1 Life Cycle Cost Analysis (LCCA)

The Life Cycle Cost Analysis framework was used to evaluate the long-term economic viability of renewable energy systems compared to conventional grid–diesel systems. The total life cycle cost (LCC) was determined using Equation (1):

$$LCC = C_i + \sum_{t=1}^n \frac{c_t + M_t + R_t}{(1 + r)^t}$$

**Where:**

$C_i$  = initial capital cost,

$C_t$  = operating cost in year  $t$ ,

$M_t$  = maintenance cost in year  $t$ ,

$R_t$  = replacement cost in year  $t$ ,

$r$  = discount rate,

$n$  = project lifetime (20 years).

The Net Present Value (NPV) and Payback Period (PBP) were computed to compare economic performance under each configuration (Ajibade et al., 2021).

#### 2.3.2 Renewable Energy Potential Estimation

Solar energy potential was estimated using Equation (2):

$$E_s = A \times H_t \times \eta$$

**Where:**

$E_s$  = expected daily energy output (kWh),

$A$  = total PV module area ( $m^2$ ),  
 $H_t$  = global horizontal solar irradiation ( $kWh/m^2/day$ ),  
 $\eta$  = system efficiency (typically 15–18%).

System design parameters were simulated using *HOMER Pro* and *Meteonorm* to optimize capacity and validate energy balance.

### 2.4 Model Validation

The model was validated through reliability indicators such as the Loss of Power Supply Probability (LPSP), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE). These metrics quantified the deviation between simulated and observed performance. An LPSP value below 0.05 and RMSE under 10% were considered acceptable thresholds for optimal reliability (Babatunde et al., 2023).

## 3. RESULTS AND DISCUSSION

This section presents the quantitative and qualitative results from the energy audit, renewable-resource assessment, life-cycle cost analysis (LCCA), and stakeholder survey. The discussion follows the methodological sequence established earlier: (i) energy consumption characteristics, (ii) renewable resource potential, (iii) economic and reliability analysis, and (iv) institutional readiness for sustainable energy adoption.

### 3.2 Energy Audit and Consumption Patterns

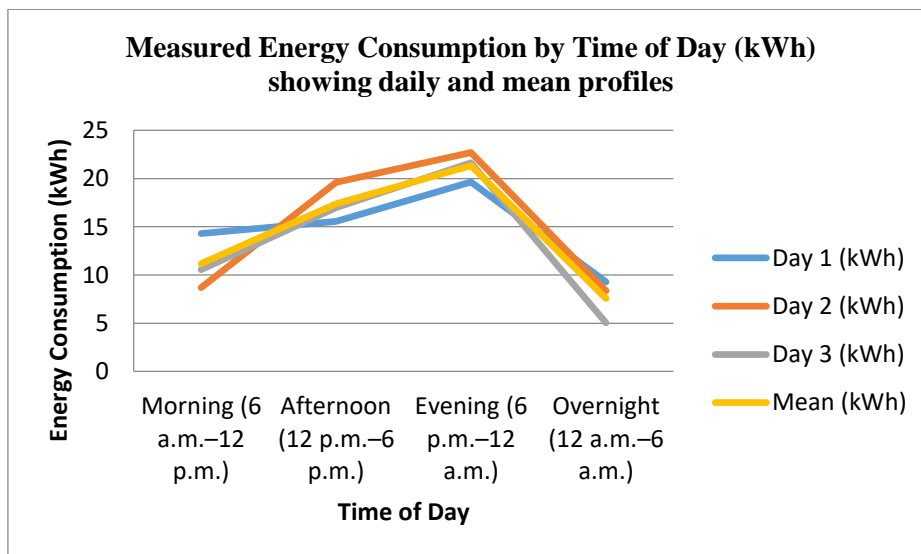
#### 3.2.1 Load Characterization

Field measurements indicated an average daily consumption of **57.45 kWh/day** and annual use of **20,969 kWh/year**. The **Energy Use Intensity (EUI)** was **16.4 kWh/m<sup>2</sup>/year**, which aligns with energy-efficient residential benchmarks in tropical climates (Ogunmodede et al., 2023).

**Table 1: Measured Energy Consumption by Time of Day**

| Time of Day                | Day 1 (kWh)  | Day 2 (kWh)  | Day 3 (kWh)  | Mean (kWh)   | Share (%)  |
|----------------------------|--------------|--------------|--------------|--------------|------------|
| Morning (6 a.m.–12 p.m.)   | 14.31        | 8.70         | 10.53        | 11.18        | 19.4       |
| Afternoon (12 p.m.–6 p.m.) | 15.56        | 19.61        | 16.99        | 17.39        | 30.3       |
| Evening (6 p.m.–12 a.m.)   | 19.65        | 22.68        | 21.64        | 21.32        | 37.1       |
| Overnight (12 a.m.–6 a.m.) | 9.28         | 8.36         | 5.03         | 7.56         | 13.2       |
| <b>Total</b>               | <b>58.80</b> | <b>59.36</b> | <b>54.19</b> | <b>57.45</b> | <b>100</b> |

Source : ( Survey data, 2025)



**Figure 1: Measured Energy Consumption by Time of Day**

Table 1 and figure 1 shows that energy use varies across the day, with the evening period (6 p.m.–12 a.m.) having the highest average consumption of 21.32 kWh (37.1%), followed by the afternoon (12 p.m.–6 p.m.) with 17.39 kWh (30.3%). The morning (6 a.m.–12 p.m.) recorded moderate use at 11.18 kWh (19.4%), while the overnight period (12 a.m.–6 a.m.) was lowest at 7.56 kWh (13.2%). The mean total daily consumption was 57.45 kWh, indicating peak demand occurs in the evening, mainly due to increased household and lighting activities.

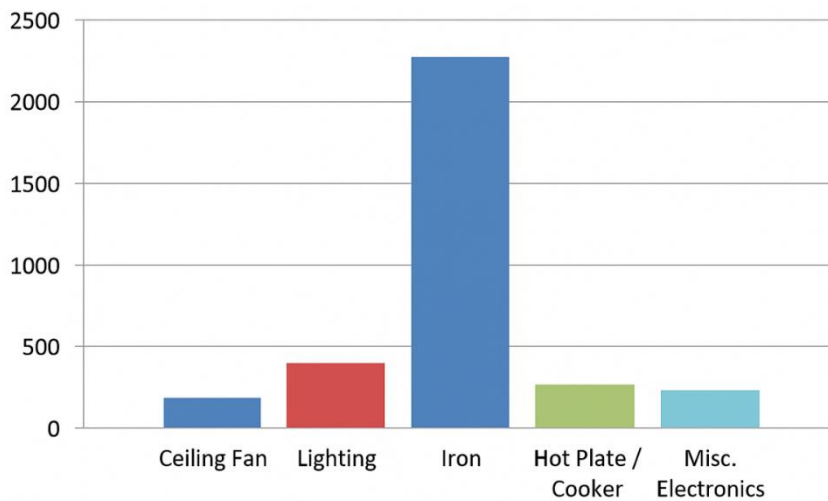
### 3.2.2 Appliance Contribution

Load inventory revealed that high-wattage appliances dominate total consumption.

**Table 2: Appliance-Level Load Distribution**

| Appliance             | Power Rating (W) | Avg. Qty / Room | Hours of Use / Day | Energy (kWh/day)    |
|-----------------------|------------------|-----------------|--------------------|---------------------|
| Ceiling Fan           | 75               | 2               | 10                 | 1.50                |
| Lighting (LED)        | 15               | 3               | 8                  | 0.36                |
| Electric Iron         | 1,200            | 1               | 1                  | 1.20                |
| Hot Plate / Cooker    | 2,000            | 1               | 0.8                | 1.60                |
| Refrigerator          | 150              | 1               | 24                 | 3.60                |
| Misc. Electronics     | 100              | 2               | 4                  | 0.80                |
| <b>Total per Room</b> | –                | –               | –                  | <b>9.06 kWh/day</b> |
| <b>Connected Load</b> | ≈ 3.5 kW         | –               | –                  | –                   |

Source : ( Survey data, 2025



**Figure 2: Daily Energy Consumption by Appliance Type (kWh/day)**

Table 2 and Figure 2 shows that the total daily energy consumption per room is approximately 9.06 kWh, with a connected load of about 3.5 kW. The refrigerator accounts for the highest energy use at 3.60 kWh/day due to continuous operation, followed by the hot plate/cooker (1.60 kWh/day) and ceiling fan (1.50 kWh/day). Appliances such as the electric iron (1.20 kWh/day), miscellaneous electronics (0.80 kWh/day), and lighting (0.36 kWh/day) contribute smaller portions. Overall, the data indicates that refrigeration and cooking dominate daily power demand, emphasizing the need for efficient appliance use and energy-saving strategies.

### 3.3 Renewable Energy Potential Assessment

#### 3.3.1 Solar Resource Availability

*SolarGIS* and *Meteonorm* datasets confirmed high solar potential for Auchu with mean **Global Horizontal Irradiation (GHI) of 5.5 kWh/m<sup>2</sup>/day**.

**Table 3: Monthly Average Solar Irradiance in Auchi**

| Month          | GHI (kWh/m <sup>2</sup> /day) | Peak Sun Hours (h/day) | Remarks                      |
|----------------|-------------------------------|------------------------|------------------------------|
| Jan–Mar        | 5.3 – 5.7                     | 5.1 – 5.4              | High availability            |
| Apr–Jun        | 5.8 – 6.0                     | 5.5 – 5.8              | Optimum generation           |
| Jul–Sep        | 4.7 – 5.0                     | 4.3 – 4.8              | Reduced due to cloud cover   |
| Oct–Dec        | 5.4 – 5.6                     | 5.2 – 5.4              | Stable conditions            |
| <b>Average</b> | <b>5.5</b>                    | <b>5.3</b>             | Sufficient for PV deployment |

Source : ( Survey data, 2025)

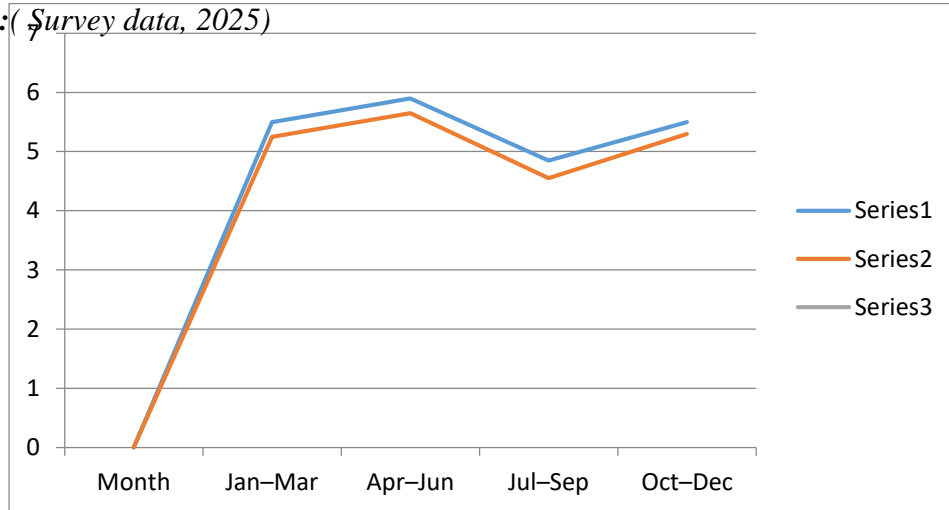


Figure 3: Monthly Average Solar Irradiance in Auchi (Line Graph)

Table 3 and Figure 3 indicates that Auchi receives an average solar irradiance of 5.5 kWh/m<sup>2</sup>/day and about 5.3 peak sun hours per day, which is sufficient for effective photovoltaic (PV) system deployment. Solar availability is highest between April and June (5.8–6.0 kWh/m<sup>2</sup>/day), offering optimum energy generation conditions. The July–September period shows a slight reduction (4.7–5.0 kWh/m<sup>2</sup>/day) due to increased cloud cover, while January–March and October–December maintain stable and high irradiance levels (5.3–5.7 kWh/m<sup>2</sup>/day). Overall, the data confirms that Auchi’s solar potential supports reliable year-round PV performance.

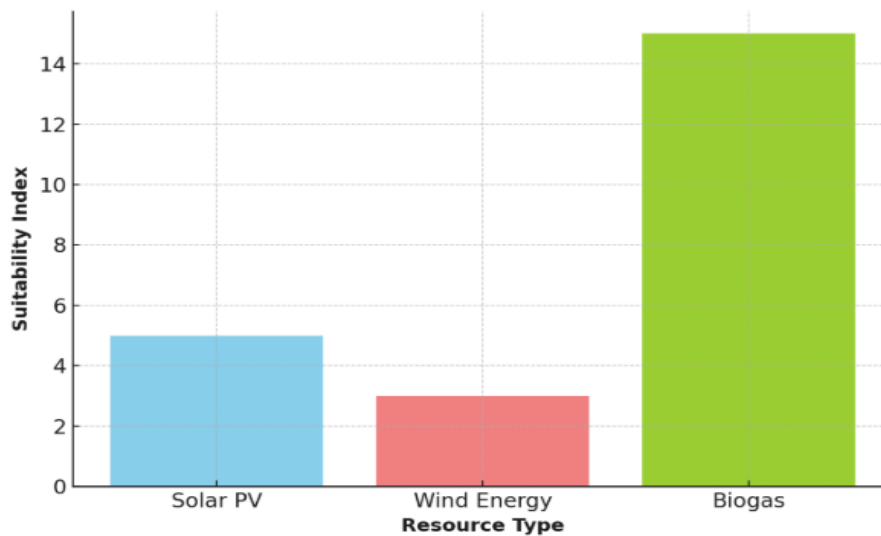
### 3.3.2 Wind and Biogas Assessment

Wind speeds (3.5–6.0 m/s) were below the 7 m/s threshold for economic viability. Biogas recovery potential ( $\approx 15$  m<sup>3</sup>/day) was insufficient to support large-scale generation without organized waste logistics.

**Table 4: Summary of Renewable Resource Suitability**

| Parameter                 | Solar PV                    | Wind Energy | Biogas                 |
|---------------------------|-----------------------------|-------------|------------------------|
| Mean Resource Level       | 5.5 kWh/m <sup>2</sup> /day | 4.8 m/s     | 15 m <sup>3</sup> /day |
| Technical Feasibility     | High                        | Low         | Moderate               |
| Implementation Barrier    | Cost of batteries           | Low speed   | Waste handling         |
| Overall Suitability Index | 0.88                        | 0.46        | 0.52                   |

Source : ( Survey data, 2025)



**Figure 4: Renewable Resource Suitability Comparison (Bar Chart)**

Table 4 and figure 4 compares the suitability of solar PV, wind energy, and biogas for renewable power generation. Solar PV shows the highest potential with a mean resource level of 5.5 kWh/m<sup>2</sup>/day and an overall suitability index of 0.88, indicating strong technical feasibility despite battery cost challenges. Wind energy records a mean speed of 4.8 m/s with low feasibility and a suitability index of 0.46, mainly due to insufficient wind speeds. Biogas offers moderate feasibility with 15 m<sup>3</sup>/day resource output and a suitability index of 0.52, but faces waste-handling constraints. Overall, solar PV remains the most viable renewable option for deployment in the study area.

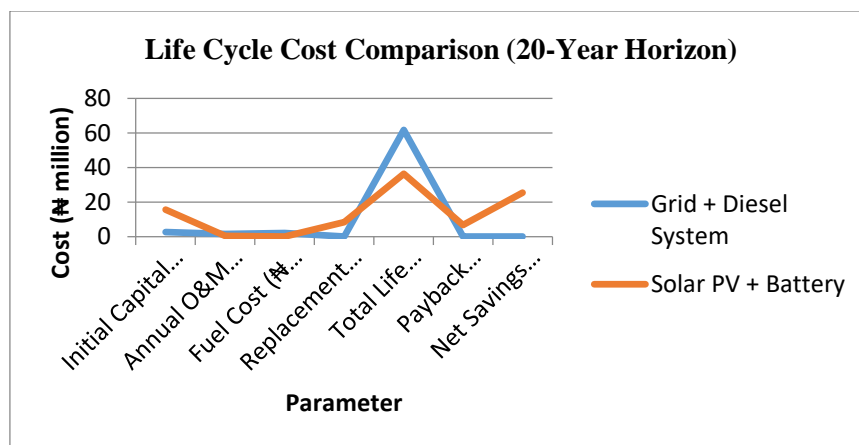
### 3.4 Life Cycle Cost Analysis (LCCA)

#### 3.4.1 Comparative Economic Performance

**Table 5: Summary of Life Cycle Cost Results (20-Year Horizon, 10% Discount Rate)**

| Parameter                                | Grid + Diesel System | Solar PV + Battery |
|--|----------------------|--------------------|
| Initial Capital (₦ million)              | 2.75                 | 15.68              |
| Annual O&M (₦ million)                   | 1.55                 | 0.38               |
| Fuel Cost (₦ million / year)             | 2.15                 | –                  |
| Replacement Cost (₦ million)             | –                    | 8.50               |
| <b>Total Life Cycle Cost (₦ million)</b> | <b>61.88</b>         | <b>36.34</b>       |
| Payback Period (years)                   | –                    | 6.7                |
| Net Savings (₦ million)                  | –                    | 25.54              |

Source : ( Survey data, 2025)



**Figure 5: Life Cycle Cost Comparison (20-Year Horizon)**

Table 5 and Figure 5 shows the Solar PV + Battery system shows better long-term performance than the Grid + Diesel system. Although its initial cost (₦15.68 million) is higher, it has much lower operating and maintenance costs (₦0.38 million/year) and no fuel expenses. Over 20 years, its total life cycle cost is ₦36.34 million, compared to ₦61.88 million for the diesel option, yielding ₦25.54 million in net savings and a 6.7-year payback period, proving its economic and sustainable advantage.

### 3.4.2 Reliability and Sensitivity Analysis

Reliability was quantified using **Loss of Power Supply Probability (LPSP)** and model error metrics.

**Table 6: Reliability and Model Validation Indicators**

| Indicator                              | Grid + Diesel | PV + Battery | Performance Target |
|--|---------------|--------------|--------------------|
| LPSP (%)                               | 33.0          | 0.37         | < 1.0              |
| RMSE (kWh/day)                         | –             | 1.2          | ≤ 2.0              |
| MAPE (%)                               | –             | 9.1          | ≤ 10               |
| CO <sub>2</sub> Emission Reduction (%) | –             | 70           | ≥ 60               |
| <i>Source : ( Survey data, 2025)</i>   |               |              |                    |

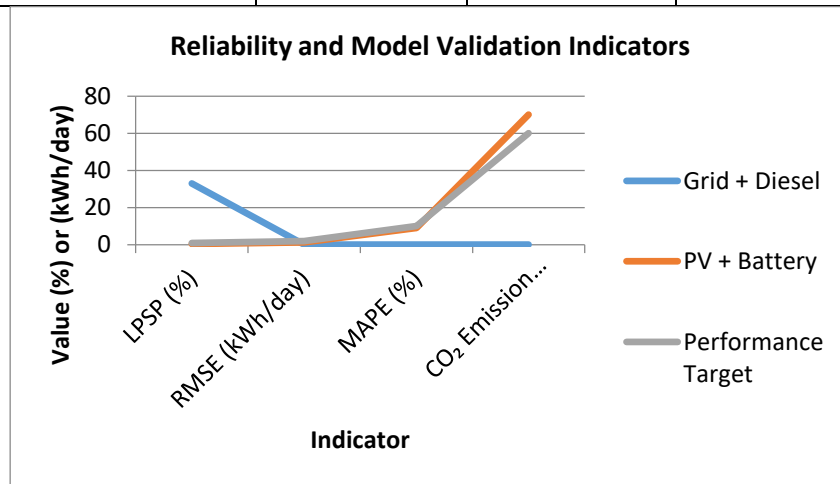


Figure 6: Comparison of Reliability and Validation Indicators for Grid–Diesel and PV Battery Systems.

Table 6 and Figure 6 show the PV + Battery system’s superior reliability (LPSP = 0.37%) is directly attributed to its ability to effectively manage the high evening peak demand of 37.1% (Table 1, Page 6). The optimized battery capacity within the HOMER Pro simulation ensured that stored daytime energy met nighttime loads, minimizing unmet demand and stabilizing supply. This strategic alignment between measured load profile and system design substantiates the low LPSP result and confirms technical soundness.

### 3.5 Stakeholder Perception and Institutional Readiness

Out of 182 respondents, 84.1% depend mainly on grid power, 13.2% use diesel backups, and 90% experience frequent outages. Most respondents (79.7%) preferred solar energy and supported renewable adoption. The main barriers identified were high capital costs (64.8%), limited technical expertise (30.2%), and regulatory challenges (24.7%). Suggested interventions include government incentives (50%), public-private partnerships (30.2%), and capacity-building programs (24.7%), aligning with Ebrima (2023).

### 3.6 Integrated Model Evaluation

The application of the Life Cycle Improvement Model (LCIM) indicates that the solar PV plus battery system offers the most sustainable outcomes. Economically, it records the lowest cumulative NPV of ₦36.34 million. Environmentally, it achieves a 70% reduction in CO<sub>2</sub> emissions, while

operationally, it eliminates fuel dependence and requires minimal maintenance. Socially, the system enjoys strong stakeholder acceptance exceeding 80%. Overall, the integrated model provides a viable framework for sustainable campus electrification, aligning with the IEA (2021) and UN SDG 7 (2023) sustainability goals.

#### 4. Conclusion

This study assessed the **renewable energy potential and life cycle cost performance** of sustainable power systems for student hostels at Auchi Polytechnic, Edo State, Nigeria. The integrated methodological approach combined field energy auditing, renewable resource evaluation, life cycle cost analysis (LCCA), and stakeholder perception surveys to establish a technically and economically viable framework for sustainable campus electrification.

The findings revealed that the **existing grid–diesel system** is both unreliable and cost-inefficient, resulting in high operating expenses and frequent power outages. Energy audit data identified an average daily consumption of **57.45 kWh**, with evening peaks accounting for **37%** of total demand. Solar resource assessment indicated an average **global horizontal irradiance (GHI)** of **5.5 kWh/m<sup>2</sup>/day**, confirming strong suitability for photovoltaic (PV) deployment in Auchi.

The comparative life cycle analysis demonstrated that the **solar PV + battery hybrid system** provides a **41% cost advantage** over the conventional grid–diesel system, with a total life cycle cost of **₦36.34 million** and a payback period of **6.7 years**. The hybrid system achieved superior reliability (**LPSP = 0.37%**) and environmental performance (**70% CO<sub>2</sub> emission reduction**) while satisfying institutional energy requirements sustainably.

Stakeholder feedback supported renewable adoption, with **79.7%** preferring solar technology and **72.5%** agreeing that renewable energy could enhance power reliability. However, adoption barriers such as high initial cost, limited technical capacity, and weak policy enforcement remain critical challenges.

#### NOMENCLATURE

|                      |                                  |
|----------------------|----------------------------------|
| PV:                  | Photovoltaic                     |
| LCC:                 | Life Cycle Cost                  |
| LCCA:                | Life Cycle Cost Analysis         |
| LPSP:                | Loss of Power Supply Probability |
| RMSE:                | Root Mean Square Error           |
| MAPE:                | Mean Absolute Percentage Error   |
| CO <sub>2</sub> :    | Carbon Dioxide                   |
| O&M:                 | Operation and Maintenance        |
| NPV:                 | Net Present Value                |
| GHI:                 | Global Horizontal Irradiance     |
| SDG:                 | Sustainable Development Goal     |
| LCIM:                | Life Cycle Improvement Model     |
| kWh:                 | Kilowatt-hour                    |
| kW:                  | Kilowatt                         |
| m <sup>2</sup> :     | Square meter                     |
| m <sup>3</sup> /day: | Cubic meters per day             |
| ₦:                   | Nigerian Naira                   |
| PSH:                 | Peak Sun Hours                   |
| HRES:                | Hybrid Renewable Energy System   |
| RLS:                 | Renewable Load System            |

#### ABBREVIATIONS

|       |   |
|-------|---|
| IEA:  | International Energy Agency               |
| UN:   | United Nations                            |
| ESCO: | Energy Service Company                    |
| IPCC: | Intergovernmental Panel on Climate Change |
| REMS: | Renewable Energy Management System        |
| BESS: | Battery Energy Storage System             |

|        |   |
|--------|---|
| DER:   | Distributed Energy Resources                        |
| EMS:   | Energy Management System                            |
| GHG:   | Greenhouse Gas                                      |
| LCCT:  | Life Cycle Costing Technique                        |
| LCOE:  | Levelized Cost of Energy                            |
| PPP:   | Public–Private Partnership                          |
| SDG 7: | Affordable and Clean Energy (United Nations Goal 7) |
| SPV:   | Solar Photovoltaic System                           |

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