Evaluation of the Long-Term Economic Implications of Deploying Renewable Energy Versus Traditional Energy Sources in a Nigerian University

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Abstract: This study evaluates the cost-benefit of installing a solar power system in the Department of Industrial and Production Engineering, Nnamdi Azikiwe University, Awka, Nigeria. With frequent power outages and the high cost of fuel-based generators, the department faces increasing energy-related expenses and operational challenges. The research garnered data of the current power sources in the department (Grid electricity and generator), and the possible cost of solar power installation. The cost evaluation was done using the Net Present Value (NPV) and Future Value formulars, for a projected period of 25-years. A comparative analysis of the three options was done, results show that the solar system, with a total cost of ₦29.33 million, is far more sustainable compared to grid electricity (₦102.19 million) and generators (₦240.98 million). The analysis confirms that solar power provides significant long-term financial savings, greater reliability, and environmental benefits. It is therefore recommended as the optimal energy solution for the department, serving both academic and practical sustainability goals.

Keyword: cost, solar power, grid electricity, generator, net present value, future value

INTRODUCTION

Nigeria has long faced significant challenges in its electricity sector, characterized by inadequate power generation, frequent outages, and a heavy reliance on fossil fuels. The national grid is often unreliable, with reports from the Nigeria Electricity Regulatory Commission (NERC) indicating that failures can occur as frequently as 10 to 15 times per month in some areas, with some outages lasting for hours. These disruptions adversely affect various sectors, including education, where tertiary institutions like public universities struggle to maintain stable electricity for academic and administrative activities.

To mitigate these issues, many institutions resort to diesel or petrol-powered generators as backup power sources. However, these alternatives come with high operational and maintenance costs, environmental degradation, and noise pollution. The Department of Industrial and Production Engineering at Nnamdi Azikiwe University is no exception. The department currently relies on both grid electricity and fossil-based generators to meet its energy needs an arrangement that has proven both costly and inefficient. In contrast, renewable energy particularly solar power offers a promising and sustainable alternative (Saurabh et al., 2025). Nigeria's geographic location provides an average solar irradiation of approximately 5.5–6.5 kWh/m²/day, making it one of the most favourable regions globally for solar energy generation. Through photovoltaic (PV) systems, sunlight can be harnessed and converted into usable electricity, potentially offering a more stable, environmental friendly and cost-effective power supply (Manolache et al., 2025, Okeagu et al., 2025).

Overview of the Nigerian Electricity Sector, it's Failures and Implications for Universities.

Electricity is a critical infrastructure for national development, industrial growth, and social welfare. In Nigeria, however, the power sector has consistently failed to meet the growing energy demands of the population and key institutions, including universities. This failure has been a result of systemic inefficiencies, policy inconsistencies, infrastructural decay, and weak governance structures (Ogunleye, 2017; Okeagu et al., 2024). Despite Nigeria's population exceeding 200 million people and the economy being one of the largest in Africa, the country's electricity generation and distribution capacity remain among the lowest per capita in the world. According to the Nigerian Electricity Regulatory Commission, Nigeria's installed electricity generation capacity is over 12,000 MW, but actual available capacity rarely exceeds 4,000 to 5,000 MW due to technical, operational, and fuel supply constraints (Andzenge, 2025). This creates a significant gap between electricity demand and supply, leading to frequent power outages across the country. Electricity generation in Nigeria is predominantly from thermal (natural gas) and hydro sources. However, actual generation falls short due to poor infrastructure and inefficient grid management (Sambo, 2009; Igbokwe et al., 2024). The challenges are compounded by an unreliable transmission network and limited investment in renewable energy options such as solar, despite Nigeria's favourable solar irradiance (Obatola, 2024; Alimi et al., 2022; Oyedepo, 2012; Ono & Okeagu, 2026).

Due to the unreliability of grid electricity, universities resort to using petrol and diesel generators. Diesel, being more efficient for high-load applications, is commonly used. However, the cost is substantial. As of 2025, the average price of diesel ranges between ₦950 and ₦1,100 per litre. A medium-sized generator consuming 20–30 litres per day can cost ₦30,000–₦42,000 daily, with monthly expenses often exceeding ₦1 million excluding maintenance (Sustainable Energy for All, 2022; Fashina et al. 2017). The national grid experiences frequent collapses over a dozen times annually resulting in widespread blackouts. These collapses are caused by poor maintenance, overloading, and inadequate transmission capacity. For universities, this results in frequent interruptions in academic work, including delayed student productivity, disrupted research in laboratories, and damage to sensitive equipment due to voltage fluctuations. Despite billions of naira invested in the sector through programs like the National Integrated Power Project (NIPP), the outcomes remain poor due to mismanagement, lack of accountability, and political interference (Akinloye and Uzedhe, 2023: Ogunleye, 2017; Oseni and Pollitt, 2014; Okeagu et al., 2025).

The introduction of the Service-Based Tariff (SBT) system by the Nigerian Electricity Regulatory Commission (NERC) in 2020 categorized electricity consumers into different "bands" (A–E) based on the number of daily supply hours received (Ugwuoke and

Onyekwelu, 2020). Customers in Band A (20+ hours) are charged the highest tariffs, while those in Band E (less than 8 hours) pay the lowest. This framework was intended to encourage fairness and incentivize Distribution Companies (DisCos) to improve supply reliability.

However, in practice, many institutions, including universities, face challenges under this system. Despite being placed in higher bands often Band B or Band C universities frequently do not receive the promised hours of supply. This results in a mismatch where they pay higher tariffs without corresponding service reliability. For example, a department expecting 16–20 hours of supply under Band B may in reality receive only 8–10 hours.

Concept of Cost-Benefit Analysis (CBA)

Cost-Benefit Analysis (CBA) is a systematic approach used to evaluate the financial and economic feasibility of a project by comparing the expected costs against the anticipated benefits over a specific time frame. It helps decision-makers determine whether an investment is worthwhile by assessing whether the benefits outweigh the costs, and if so, by how much. CBA is particularly useful in infrastructure and energy projects, where large upfront investments are typically required and long-term savings are projected. In the context of energy planning, CBA can guide institutions in choosing between maintaining conventional energy sources (e.g., grid power and diesel generators) or transitioning to alternative solutions like solar power. Key Components of CBA includes:

1. **Initial Capital Costs:** These include all upfront expenses such as equipment purchase, installation, and setup (Mishan and Quah, 2020).
2. **Operating and Maintenance Costs:** Recurring expenses like servicing, repairs, and replacements over the project's life. (Akinyele and Rayudu, 2014; Okeagu et al., 2025; Mgbemena & Okeagu, 2023).
3. **Savings and Benefits:** Includes fuel savings, reduced electricity bills, productivity gains, and environmental improvements. (Sovacool, 2011)
4. **Payback Period**: The time required for cumulative savings to equal the initial cost.
5. **Net Present Value (NPV):** The present value of benefits minus the present value of costs over the project's lifespan. (Mishan and Quah, 2020)
6. **Benefit-Cost Ratio (BCR):** The ratio of total discounted benefits to total discounted costs; BCR is greater than 1 means viable (Shand et al., 2025).
7. **Discount Rate**: Used to reflect the time value of money when discounting future costs and benefits (Nnaemeka et al., 2022).

Previous Work done

Several studies in Nigeria have applied CBA in evaluating the feasibility of solar energy systems within university environments, recognizing the financial strain imposed by unreliable grid power and diesel dependence.

Olaniyan et al., (2018), conducted a cost-benefit analysis for deploying solar-powered street lighting systems at Obafemi Awolowo University. Their study revealed that while the initial installation cost was high, the long-term operational cost was significantly lower than using diesel-powered lighting systems. The payback period was estimated at less than 5 years. Akinyele and Rayudu (2014), analysed the techno-economic viability of decentralized solar PV systems for powering laboratory buildings in Nigerian tertiary institutions. They found that solar PV systems provided significant cost savings over a 10-year period, with reduced environmental impact and increased energy reliability. Olawole et al., (2020), carried out a comparative economic analysis between diesel and solar-powered systems for administrative buildings at the University of Ibadan. Their findings highlighted that solar

systems, despite their upfront costs, became more cost-effective after the fourth year due to increasing diesel prices and recurring generator maintenance costs.

Agboola and Emmanuel (2021), evaluated the CBA of a hybrid solar-diesel system in a Federal Polytechnic and concluded that hybrid systems can be an effective transitional solution until full solar deployment is feasible. These studies consistently show that the use of solar energy, especially in university environments, is not only environmentally beneficial but also economically viable in the long term. The financial savings, combined with increased energy reliability, make solar power an attractive solution for addressing the power challenges faced by educational institutions in Nigeria. (Chiedu et al., 2022)

Despite this potential adoption of solar energy within university departments remains limited. One major deterrent is the high initial capital investment required, coupled with limited empirical data demonstrating long-term financial viability. A detailed cost-benefit analysis (CBA) could provide the necessary insight into whether transitioning to solar energy is economically feasible for departments like Industrial and Production Engineering department. This will require analysing the financial implications of installing a solar power system such that it is tailored to the department's needs. Comparing the costs and benefits of adapting solar energy source with those of conventional power sources to determine the viability of adopting solar energy for long-term use.

METHOD

Load Assessment and Energy Demand Estimation

The raw energy demand for the appliances in the department of industrial and production engineering Awka, without any adjustment. is calculated as below:

Using load assessment formula:

$$total\ load = power\ rating\ of\ each\ appliances \times quantity \times Utilization$$

Table 1. load assessment for the department of industrial and production engineering

s/n	Load	Quantity	Power rating (W)	Total power	Time usage (hours)	Total load (kWh/day)
1	Refrigerator	2	250	500	8	4000
2	ORL 18 inches fan	8	80	480	8	3840
3	32inches Led TV	6	40	240	5	1200
4	Desktop	2	150	300	8	2400
5	Laptop	4	90	360	8	2880
6	Printer	3	50	150	4	600
7	Lighting	20	10	200	8	1600
8	Decoder	4	25	100	5	500
9	Standing fan	2	80	160	8	1280
10	Other loads (mobile chargers)	16	10	160	8	1280
Total				2650		20kWh/day

Cost Evaluation of 5KVA Solar Inverter

Table 2: Cost estimation of 5KVA solar inverter

Component	Initial capital/cost	Annual Replacement	Annual Maintenance and Labor
Solar panel (10 bifacial 420w)	80,000*10= 800,000	___	
Distilled water	15000	___	30,000
Tubular battery (4)	295,000*4= 1,180,000	___	
5Kva inverter	393,000	___	
100 Amp charge controller	200,000	___	
DC breaker	16,000	___	
Aluminum profile 18ft*4pcs	10,500*4= 42,000	___	
Cable 10mm 45yards	5,500*45= 247,500	___	
Cable 4mm 30 yards	800*30= 24,000	___	
Battery rack	60,000	___	
Labor cost	400,000		
Accessories	68,300	20000	
Total	3,445,800	20,000	30,000

Total = N3,495,800

PV panels have a lifespan of 25 years

Lifespan of tubular battery is 4-5 years. If well maintained, their service year can be more. Assuming 5 years life span for batteries; for 25 years, batteries will be replaced 5 times. Applying net present value (NPV) to calculate the total cost for a period of 25years (Mishan and Quah, 2020)

$$FV = PV(1+r)^n$$

Let's assume an interest or 20% for each cycle on the batteries, for the remaining 4 cycles it will be 20% × 4 = 80%. Total cost of batteries for 25 years period at 80% interest;

$$FV = 1180000(1+0.8)^5 = ₦22,296,902.4$$

If the system is well maintained, all other initial cost remains constant for the period of 25 years.

Adding cost of batteries for 25 years period to initial capital as obtained from Table 2

Overall cost = ₦22,296,902.4 + 800,000 + 15000 + 393,000 + 200,000 + 16,000 + 42,000 + 247,500 + 24000 + 60,000 + 400,000 +68,300 = ₦24,562,702.4

Overall cost + annual replacement +annual maintenance = 20000+30000 = ₦50000

Total cost for 25 years at 20% Increment $= 50000(1+0.2)^{25} = ₦4,769,810.83$

Overall cost for a period of 25 years = ₦24,562,702.4 + ₦4,769,810.83 = ₦29,332,513.23

Gasoline generator

Table 3 shows the cost evaluation of a 5KVA gasoline generator, using Firman ECO7990ES petrol generator.

Table 3 Cost Analysis of a 5KVA Gasoline Generator

Component	Initial Capital (#)	Annualized Replacement (₦/yr.)	Annual Maintenance and Labor (₦/yr.)	Annual Fuel (₦/yr.)
Generator	850,000	___	250,000	1,976,000
Engine Oil	7,500	180,000	___	___
Spark plug	___	24,000	___	___
Total	857,500	204,000	250,000	1,976,000

In Table 3, the initial cost referred to here is the cost of purchase. The cost of a 5KVA Using Firman ECO7990ES petrol generator (copper) goes for #850,000 (sumecplaza.com) and also the largest capital is spent on fuelling which accrual to the above sum (#1,976,000) on an 8 litres of fuel per 8 hours running each day on a 5 days week. The annual maintenance and labour cost are the cost for the workmanship for a period of one year. A 5KVA petrol generator can last up to 2000 – 3000hrs that is an average of 5 years if properly managed. If the gasoline generator is operated for 8hours daily on 5-days week;

Weekly working hour = 5 X 8 = 40 hrs If the generator is shut down for maintenance during holidays and assuming a period of 3 months for maintenance throughout the year;

Number of weeks for maintenance and repairs = $\frac{3 \text{ months}}{12 \text{ months}}$ x 52weeks = 13weeks

Yearly operating week = 52 – 13 = 39 weeks

Hours of operation in a year = 39 X 40 = 1560 hrs.

If the gasoline generator last about 3000 hours;

Life span = $\frac{3000}{1560}$= 1.9 years (approximately 2 years) if properly maintained. For 25 years period, number of generators that will be bought =$\frac{25}{1.9}$ = 13.2

That is 13 gasoline generators will be used for a period of 25 years.

Applying net present value (NPV) to calculate the total cost for a period of 25years

$$FV = PV(1+r)^n$$

Assuming an interest value of 20%; total cost of 13 petrol generators initial cost

FV = $857,500(1 + 0.2)^{13}$= ₦9,174,667.36

From the table, total annual cost = Annualised Replacement + Annual Maintenance and Labour + Annual Fuel = ₦204,000 + ₦250,000+ ₦1,976,000 = ₦2,430,000

Total annual cost = ₦2,430,000 for a period of 25 years at 20% increment;

Total cost = 2,430,000 (1 + 0.2)25 = ₦ 231,812,806.45

Overall total cost if a petrol generator were to be used to power the department for 25 years will be: ₦9,174,667.36 + ₦231,812,806.45 = ₦240,987,473.8

EEDC (grid electricity) cost evaluation

Base data. Tariff = #206 (band A tariff rate)

Daily energy consumption =20Kwh/day $\times$ 206 = #4,120

weakly energy consumption = 4120 $\times$ 5=20,600

Annual energy cost = 20,600 ×52 = ₦1,071,200
Increment rate = 20% per year
Period = 25 years.
Applying equation 1
$$FV = 1071300(1 + 0.2)^{25} = ₦102,197,966$$

Benefit Cost Ratio (BCR)
The BCR is calculated using the equation as shown (Alimi et al., 2022).
$$BCR = \frac{PV(benefits)}{PV(costs)}$$
Solar savings vs generator = ₦240,987,473.80 – ₦29,332,513.23 = ₦211,654,960.57
BCR = 211,654,960.57 ÷ 29,332,513.23 = 7.22.
Solar savings vs Grid = ₦102,197,966 – ₦29,332,513.23 = ₦72,865,452.77
BCR = 72,865,452.77 ÷ 29,332,513.23 = 2.48.

RESULT AND DISCUSSION
Load Estimation
The first set of results comes from the departmental energy audit and load assessment. The audit confirmed that the average daily energy consumption of the Department of Industrial and Production Engineering is approximately 14 kWh per day (after applying the diversity factor). This figure is the foundation for designing the solar system and is directly tied to research Objective 1, which sought to determine the energy needs and appropriate system size.

Breaking down the energy use by appliance category (based on Table 3.1 data above): the largest contributors to the load were the cooling and ventilation equipment. For instance, the two office refrigerators consume about 4.0 kWh/day combined, accounting for roughly 20% of total usage (the highest single category). The array of electric fans (ceiling and standing fans together, eight in number) was the next significant load, using an estimated 5.1 kWh/day (around 25–26% of total). Computers (desktops and laptops combined) contributed approximately 5.3 kWh/day (~27%), indicating the importance of powering ICT equipment. Lighting (20 fluorescent tubes) was a smaller fraction at roughly 1.6 kWh/day (8%). Other devices like printers, TVs, and decoders each individually consumed <5% of the total. Figure 1 visualizes the energy demand distribution among key appliance groups.
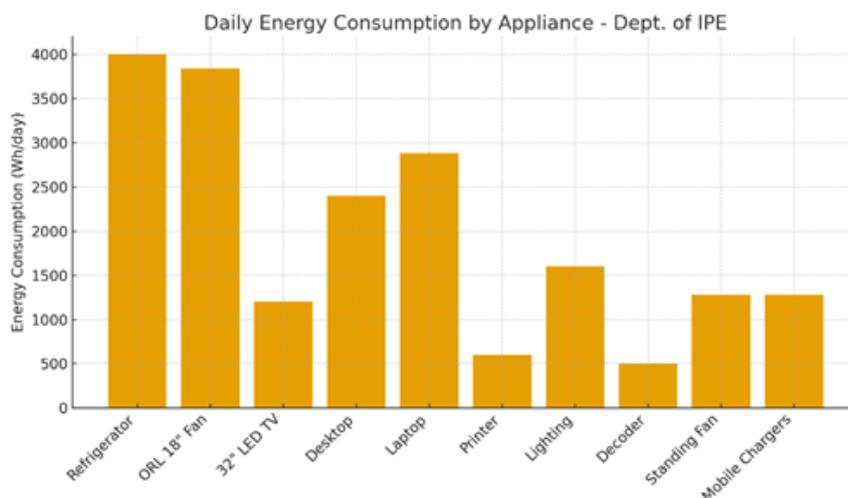

Figure 1. Daily Energy Consumption by Appliance

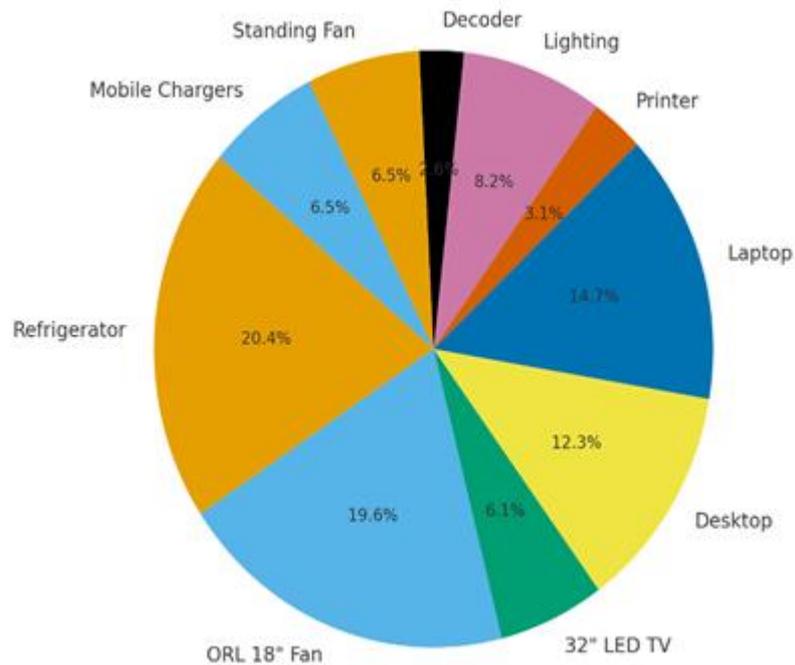Percentage Contribution of Appliances to Total Energy Consumption

Figure 2. Load Assessment by Percentage

These results highlight that refrigeration and cooling are the biggest energy drivers in the department, a finding consistent with expectations in a warm climate. Notably, the refrigerators alone draw more energy than all lighting fixtures in the department. This has practical implications: any power solution (solar or otherwise) must ensure reliable service to these critical loads to maintain a functional academic environment (for instance, keeping lab samples cool or providing comfortable ventilation for students and staff). The load audit also validates the sizing choice for the solar system – the 5 kVA inverter and 10-panel array were predicated on this 14 kWh/day requirement, which the results confirm as accurate. In essence, the department's energy demand can be met by a 5 kVA solar installation under typical conditions, with a modest buffer for peak times.

Comparative Lifecycle Cost Analysis

Having the gotten the evaluation results as presented below, we directly compare the 25-year lifecycle costs of the solar power system versus conventional energy sources. The comparison can be made both in absolute Naira terms and in proportional terms:

In absolute terms, as already noted, the 25-year costs are:
1. **Solar PV:** ₦29.3 million
2. **Grid Electricity:** ₦102.2 million
3. **Petrol Generator:** ₦241.0 million

These values conclusively show that the solar option is the least costly over the long term. Figures 3 and 4 encapsulated this finding visually. The generator option would drain departmental finances drastically, while grid reliance also accumulates to a very high cost. Solar, despite the upfront investment, yields a much flatter cost trajectory.

To illustrate the composition of costs, Figures 3 and 4 shows a proportional breakdown of each option's share of the total combined expenditure if one were to spend 25 years cycling through all three (for comparison's sake):
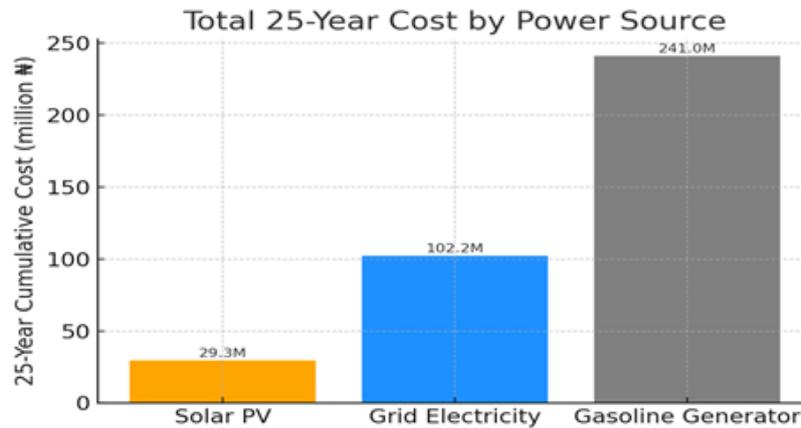

Figure 3. Bar Chart Comparing Total Projected Expenditure (in ₦ millions) Over 25 Years for the Three Energy Options Under Study
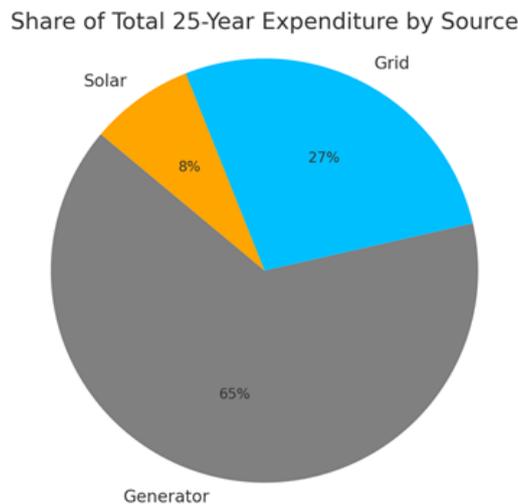

Figure 4. Proportional Distribution of Total 25-Year Costs Among the Three Options

In Figure 4, one sees that over 60% of the long-term cost burden comes from generators alone. This confirms that heavy dependence on generators is financially unsustainable for the department. The solar slice is under 10%, emphasizing again how small the solar costs are in comparison. Another perspective: for every ₦1 spent on solar, about ₦3.5 would be spent on grid power or ₦8 on generator power for the same energy delivered.

It is also insightful to examine the year-by-year trend of costs (cumulative) to see how quickly each option's expenses grow. Figure 5 presents the cumulative cost curves for each option across the 25 years:
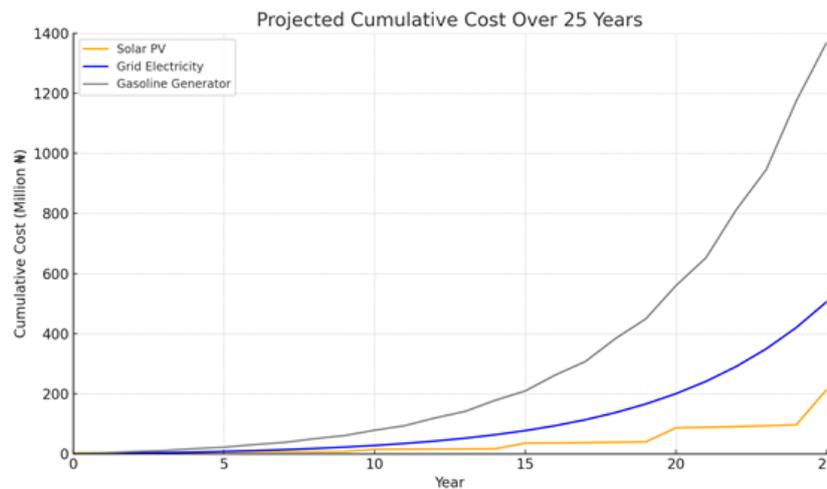
Figure 5.Projected Cumulative Cost Curves for Solar PV (orange), Grid (blue), and Generator (gray) from Year 0 to Year 25

From Figure 5, we observe: - By Year 5, Solar's cumulative cost has barely risen after the initial payment (just maintenance and one battery replacement), whereas grid and generator costs have already grown significantly (generator >₦15M vs solar ~₦5–6M by that point). - By Year 10, the gap widens: the generator curve shoots upward (due to fuel inflation), crossing ₦50M, while grid is around ₦15–20M, and solar perhaps ₦10M. - Beyond Year 15, generator costs explode non-linearly, reflecting how fuel costs dominate. Grid costs also climb but at a lower exponential rate. Solar remains largely flat after replacing the second set of batteries (years 10 and 15 replacements are seen as small bumps).

This dynamic perspective reinforces the earlier static comparisons by highlighting the economic advantages of long-term cost stability associated with solar energy systems. Once the initial investment is recovered (typically within 5–7 years through accumulated savings), the department would be shielded from the persistent fluctuations and rising costs that characterize conventional energy sources such as grid electricity and generator use. This aligns with broader economic evaluation approaches which emphasize long-term income flow and capitalization of returns in assessing investment viability (Odumodu & Odimegwu, 2019). In contrast, continued reliance on conventional energy sources would likely lead to a rapidly increasing financial burden, potentially exceeding the department's budget growth over time. Such financial pressures can also affect institutional efficiency and decision-making processes, as organizational outcomes are closely tied to strategic planning and resource management (Umeokafor, 2026). Consequently, the comparative analysis suggests that solar energy provides a more sustainable and financially predictable option for the department in the long run.

BCR was computed to complement the NPV. As reported earlier, the BCR > 1 in all comparisons involving solar: BCR = **7.2** (using generator costs as the benefit), meaning for every ₦1 spent on solar, about ₦7.2 of generator costs are avoided. This very high ratio underscores the economic inefficiency of the generator status quo. BCR = 2.5 (using grid costs as the benefit), meaning every ₦1 on solar saves ₦2.5 of grid electricity payments. This indicates a 150% return in terms of cost savings, which is still a strong economic case. It is rarer for grid parity to be in favor of solar without subsidies, but given the high tariffs and expected increases, the BCR being well above 1 shows solar is economically justifiable even against public power supply.

In summary, the comparative analysis finds that installing the solar system is decisively the most cost-effective strategy over the 25-year horizon. The margin is so large (tens to

hundreds of millions saved) that even if our assumptions are stressed (for instance, if solar panels needed replacement earlier, or if fuel prices stabilized), the conclusion would likely hold. This result forms the economic rationale for recommending a transition to solar.

CONCLUSION

This study's cost–benefit analysis concludes unequivocally that solar PV is the optimal energy solution for the Department of Industrial and Production Engineering. The main findings includes over 25 years solar PV incurs the lowest total cost (by a wide margin) and achieves a positive Net Present Value and Benefit–Cost Ratio, whereas continued reliance on diesel or grid power yields negative NPVs and unfavourable BCRs. These quantitative results are supported by qualitative benefits, a solar system would eliminate frequent blackouts and generator noise, vastly improving the academic environment. However, both the financial metrics and the practical observations indicate that the department should adopt solar PV as a sustainable long-term energy source.

The use of cost–benefit analysis was critical in reaching these conclusions. By quantifying all costs (capital, operating, fuel, maintenance) and all benefits (fuel savings, reduced grid purchases, avoided downtime) in present-value terms, the study provides a clear, evidence-based basis for decision-making. This aligns with best practices noted in energy investment planning, rigorous CBA reveals the true economic returns of infrastructure projects and prevents wasteful expenditure. In the university context, such a structured analysis demonstrates that investments in renewable energy infrastructure can be clearly justified. In other words, CBA has shown here that the benefits of switching to solar (financial and academic) far outweigh its costs; this provides a strong justification for action by university managers.

Finally, the findings underscore the long-term value of solar energy for higher-education settings. Although the initial capital outlay is significant, the payoff in terms of steady power, predictable budgets, and reduced carbon footprint becomes evident over the system's life. In a university where research, lectures, and digital services cannot tolerate frequent outages, the strategic value of a solar installation extends beyond mere cost savings. It supports academic excellence and institutional resilience. In the context of Nigeria's growing electricity challenges, deploying solar at the departmental level not only meets immediate energy needs but also positions the university as a leader in sustainability with benefits that will accrue over many years.

In addition to departmental applications, the findings of this study highlight the potential of solar photovoltaic (PV) systems in student hostels and private lodges within and around the university environment. These facilities face similar challenges of unreliable grid supply and dependence on costly generators, which directly affect students' welfare, study hours, and living expenses.

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