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Transitioning from Diesel to Solar: A Comparative Cost Analysis for Electricity Generation at Federal Polytechnic Nekede, Owerri.

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ABSTRACT : *Inadequate electric power security in Nigeria has imposed significant costs in all sectors. This research presents a comparative cost analysis of electricity generation from diesel generators and a proposed photovoltaic (PV) power plant at the Federal Polytechnic Nekede, Owerri. Given the ongoing challenges in Nigeria's electricity supply sector, including frequent outages and high operational costs of diesel generators, this study aims to assess and compare the economic viability of these two energy sources. A life cycle costing approach was employed to analyze the total costs of ownership over the lifespan of each energy generation method, including initial investment, operating, maintenance, and fuel costs. The results indicate that the empirical generation cost (EGC) from existing diesel generators is approximately , while the theoretical generation cost (TGC) associated with a zoned arrangement of diesel generators is estimated at . In contrast, the proposed solar photovoltaic power plant demonstrates a significant cost advantage, with a unit cost of electricity estimated at . These findings not only underline the high economic burden of relying on diesel- powered generators but also highlight the potential for renewable and reliable energy solutions to provide sustainable and cost-effective electricity for educational institutions in Nigeria.*

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I. INTRODUCTION

Every developed economy is built with the technical realization that a sustained availability of quality and affordable electricity in its various forms of generation is fundamental to the provision of jobs, transportation, industrialization, health services, education, housing, clean water, and good sanitation (Labo, 2010).

Although Nigeria is blessed with large amount of renewable energy resources like hydropower, solar, wind and biomass, extensive substitution of poor public electricity supply with high polluting self-generated power prevails (Iwuamadi *et al.*, 2014). With the crisis in the sector as result of the relatively poor generating capacity and fragile transmission/distribution systems, Nigeria is experiencing electricity poverty with meager electricity per capita of $140KWh$ against a projected requirement of $1{,}110KWh$ (Iwayemi, 2008; Oseni, 2011; Adenikinju, 2008). These problems are generally categorized as energy poverty – the lack of or limited access to affordable and available electricity (Iwuamadi *et al.*, 2020). It is widely accepted that there is a strong correlation between socio-economic development and the availability of electricity.

Federal Polytechnic Nekede, Owerri, like many institutions of higher learning in Nigeria, relies heavily on in-facility captive power plants to meet their electric energy requirements. These captive power plants, mostly powered by diesel engines help the institution render their academic and administrative services with minimal disruption to service delivery and ensure prompt and efficient customer services. However, the increasing cost of diesel fuel and the environmental concerns associated with diesel generator emissions have made it necessary to explore alternative sources of energy. Photovoltaic (PV) plants are a viable option for renewable energy generation, and their overhead cost has been decreasing over the years. The objectives of this study are to develop an empirical comparative cost analysis of electricity from existing diesel generators, a proposed diesel generators based on zoning and a proposed $5.56MW$ solar photovoltaic power plant (SPPP) in Federal Polytechnic Nekede, Owerri.

Existing Electricity Supply in FPNO

The Federal Polytechnic Nekede, Owerri (FPNO) as an example is currently operating on two major modes of electric power supply namely utility and diesel generators.

- ***Utility Supply Structure***

Electric power is supplied to the Federal Polytechnic Nekede, Owerri from Egbu road Injection substation through a switchyard within institution premises. The switchyard houses three $33/11kV, 5MVA$ step down transformers, metering equipment and oil circuit breakers that protect the transformers. One of the $33/11kV, 5MVA$ transformer supplies power to the campus Medical Centre while the other two transformers supply power to the rest of the institution community both administrative and hostel buildings. The various $33/0.415kV$ secondary substations are fed from the switch substations through Ring Main Units (RMU) and

$95mm^2$ underground armored Feeder Lines. Each feeder begins and ends at a switch substation through oil circuit breakers (OCB). That is each Feeder is connected on either side through OCB and power can be fed from any side, depending on the load distribution required. Each of these switch substations is equipped with South Wales Gear and uses a sectionalized busbar system with section switches (oil circuit breakers) and other switch ways for incoming and outgoing feeders.

- ***Diesel Generators Structure***

The frequent failures and unavailability of supply from the utility source has made the institution depend mostly on diesel generators for electricity supply to most of its facilities (Anyaehie and Iwuamadi, 2020). This development has led to the institution running 30 different generators with varying capacities for different facilities and as a result, there are 23 functional different generating sets running simultaneously almost daily, while 7 are non-functional. Currently, the total installed capacity of the generators is $4427.5KVA$ while the functional/available capacity is $2777.5KVA$.

Table 1: Generators Location, Rating and Condition in the Institution as at February 2024

S/N	LOCATION	RATING (kVA)	CONDITION
1	New water scheme near Plant house	50	Functional
2	Medical Centre	100	Functional
3	Staff school	60	Functional
4	Fabrication	500	Functional
5	1000 capacity auditorium (MIKANO Substation)	500	Functional
6	1000 capacity auditorium (Perkins)	30	Functional
7	Hostel A	200	Functional
8	SBMT	200	Functional
9	SEDT	200	Functional
10	Water factory	100	Functional
11	Water factory	60	Functional
12	Hostels B and C	100	Functional
13	Humanities	100	Functional
14	Food Technology building	100	Functional
15	Microfinance bank	100	Functional
16	Library	100	Functional
17	PTDF	60	Functional
18	Bookshop	9	Functional
19	Stores	18.5	Functional
20	Works Department	30	Functional
21	CBT	100	Functional
22	Skill G	60	Functional
23	IPC	30	Functional
24	Water Scheme near Rectory	50	Non-Functional
25	Water Scheme near Plant house	50	Non-Functional
26	Rectory	500	Non-Functional
27	Plant house (Outdoor)	500	Non-Functional
28	1000 capacity auditorium	200	Non-Functional
29	Engineering Complex I and II	100	Non-Functional
30	Weekend Program	250	Non-Functional

The high cost of fuelling and maintenance of these generators can be imagined to have caused indiscriminate use of several *PMS* powered generators. The generators have a very high operation cost and are not clean source of energy either.

Proposed Alternative Electricity Supply Structure in FPNO

Furthermore, most of these generators especially those rated above $200KVA$ are not optimally loaded thereby making the Polytechnic spend more on their running and maintenance.

- ***Proposed Diesel Generators Structure Based on Zoning***

Anyaehie and Iwuamadi (2020) proposed an efficient zoning arrangement to reduce the number of active generators running in the campus. This will greatly reduce the running and maintenance cost of these generators without affecting the efficiency, loading capacity and power supply to the campus

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Table 2: Proposed Zoning Arrangement of Generators (Anyaehie and Iwuamadi, 2020)

ZONE	**ZONE 1**	**ZONE 2**	**ZONE 3**	**ZONE 4**	**ZONE 5**
CAPACITY	$500KVA$	$500KVA$	$500KVA$	$250KVA$	$100KVA$
FACILITY ZONED TO BE SUPPLIED	Rectory, Registry, Bursary, SIAS, SEDT, Hospitality, SHSS, IPC and Science Tech.	SET Auditorium, ASUP, SUG block, Foundry, Engineering Labs and workshops, Ceremonial Ground, TEDC, MIS, Skill-G labs.	Library, 1000 capacity Auditorium, SBMT (Classrooms and office), Old admin block, Fuel dump, Hostels A, B, C, Staff School.	Evening Programme, Weekend Programme, CBT Centre	Medical Centre, Works division, Security unit, Water Factory.

- ***Proposed 5.56MW solar photovoltaic power plant***

To alleviate inefficiencies posed by the electricity challenge, Iwuamadi, Anyaehie and Nwadike (2022) proposed a 5.56 MW SPPP design with regard to the energy demand of the Institution estimated to be 4.275 MW. The design has the total watt peak rating of PV modules as 8462.45KW with a total number of **26865** 315W PV modules and battery capacity of 109341.26 Ah arranged to be connected to **11** number, *600KVA/380V – 415V/3phase PSC Solar UK (KR33600)* Xantra Online Inverter/Charger Technical Specs.

Table 3: Proposed Zoning Arrangement of Inverters

ZONE	**ZONE 1**	**ZONE 2**	**ZONE 3**	**ZONE 4**	**ZONE 5**
Number of Solar Power Inverters per Zone	**3**	**3**	**2**	**2**	**1**
FACILITY ZONED TO BE SUPPLIED	Rectory, Registry, Bursary, SIAS, SEDT, Hospitality, SHSS, IPC and Science Tech.	SET Auditorium, ASUP, SUG block, Foundry, Engineering Labs and workshops, Ceremonial Ground, TEDC, MIS, Skill-G labs.	Library, 1000 capacity Auditorium, SBMT (Classrooms and office), Old admin block, Fuel dump, Hostels A, B, C, Staff School.	Evening Programme, Weekend Programme, CBT Centre	Medical Centre, Works division, Security unit, Water Factory.

METHODOLOGY

The study used a life cycle costing approach to estimate the total cost of electricity generation from diesel generators and SPP plants. This approach assessed the total cost of ownership of the power sources over its entire life cycle which encompasses all phases from initial acquisition through operation and maintenance, to decommissioning and disposal. The costs considered included:

a. Initial investment costs: The cost of purchasing and installing the diesel generators or SPP plants.
b. Operating costs: The cost of fuel, maintenance, and repairs for the diesel generators or SPP plants.
c. Total cost of ownership: The total cost of owning and operating the diesel generators or SPP plants over their lifespan.

The data used in this study was collected from various sources, including:

i. Published literature on the cost of electricity generation from diesel generators and PV plants.
ii. Data on the average cost of diesel fuel in Nigeria.
iii. Data on the average cost of photovoltaic panels in Nigeria.
iv. Data on the average cost of maintenance and repairs for diesel generators and PV plants.

COST MODEL FORMULATION

The cost of electricity (Naira/KWh) generated by different sources is a calculation of the cost of generating electricity in naira at the point of connection to a load terminal. Typical operating costs of generating electricity from diesel generator consist mainly of operation, maintenance and repair costs, fuel costs, site and overall system supervision while that of SPP consist of maintenance and repairs. The following assumptions were adopted for the analysis:

a. The diesel generators were assumed to operate under ideal optimum conditions without breakdowns throughout their normal working life.
b. The diesel generators were assumed to operate for 9 hours (8am to 5pm) daily for job efficiency and reliability since the utility supply is frequently down.
c. Maintenance is effective enough to minimize the effects of depreciation.

Terminologies and Notations

The terminologies and notations adapted in this study are as follows:

EGC – Empirical generation cost (N)
aCF – Annual cost of fuelling (N)
TGC – Theoretical generation cost (N)
aCRS – Annual cost of routine services (N)
TCP – Total cost of procurement (N)
mFC – Monthly fuel consumption (N)
mTO – Total time of operation per month (Hours)
mCF – Monthly cost of fuelling (N)
UCP_i – Unit cost of generator procurement (N)
aCPR – Annual cost of parts repairs (N)
CFe_i – Cost of fuelling existing generator ***i*** per day (N)
aCM – Annual cost of maintenance (N)
aTO – Total time of operation per annum (Hours)
aMC – Annual miscellaneous cost (N)
CFp_i – Cost of fuelling proposed generator ***i*** per day (N)
mCF – Monthly cost of fuelling (N)
$aCRS_p$ – Proposed annual cost of routine services (N)
mCF_p – Proposed monthly cost of fuelling
$aCPR_p$ – Proposed annual cost of parts repairs (N)
aMC_p – Annual miscellaneous cost (N)
aCM_p – Proposed annual cost of maintenance (N)
UCE – Unit cost of electricity (N)
ToP – Total power (KW)

COST MODEL

The cost model analysis for the three varied electricity generation sources was done based on the current costing in naira.

- ***Cost Model of Existing Diesel Generators***

Empirical generation cost per annum is a cumulative sum of the total cost of procurement of the generating sets and the function of annual cost of fuelling and annual cost of maintenance. That is:

$$EGC = \sum [TCP, f(aCF, aCM)] \quad (1)$$

Where,

$$TCP = \sum_{i=23}^{n} UCP_i$$

$$aCF = 12(mCF)$$

$$mCF = 20\sum_{i=23}^{n} CFe_i$$

$$aCM = f(aCRS, aCPR, aMC)$$

$$ToP = 0.8 \times 2777.5KVA = 2222KW$$

$$aTO = 9hrs \times 20days \times 12months = 2160hrs$$

Procurement cost all existing generators (functional and not functional) were considered with the current pricing as shown in Table 4.

Table 4: Procurement cost of existing generators.

Rating (KVA)	***Number***	***Unit price (N)***	***Total price (N)***
500	4	93,580,300	374,321,200
250	1	25,000,000	25,000,000
200	4	22,500,000	90,000,000
100	9	20,000,000	180,000,000
60	4	14,750,000	59,000,000
50	3	12,900,000	38,700,000
30	3	12,647,200	37,941,600
18.5	1	11,460,000	11,460,000
9	1	6,890,000	6,890,000
			823,312,800

Currently a litre of diesel is sold at N1250 and records obtained revealed that about 65400 litres of diesel is consumed monthly. The fuelling cost of the 23 existing and functional diesel generators was considered to have efficiently operated as shown in Table 5.

Table 5: Cost of Fuelling

Rating (KVA)	***Number (Functional)***	***Consumption per month (Litres)***	***Monthly Cost of fuelling (N)***	***Annual Cost of fuelling (N)***
500	2	8000	10000000	120000000
250*	0	0	0	0
200	3	12000	15000000	180000000
100	8	25600	32000000	384000000
60	4	9600	12000000	144000000
50	1	1920	2400000	28800000

30	3	5760	7200000	86400000
18.5	1	1280	1600000	19200000
9	1	1280	1600000	19200000
1,218	**23**	**65,440**	**81,800,000**	**981,600,000**

The data collection revealed the basic and operational information of the generators' annual cost of maintenance from January to December 2023 as **N38,675,000**.

$EGC = 823{,}312{,}800 + 981{,}600{,}000 + 38{,}675{,}000$

$= \boldsymbol{N1{,}843{,}587{,}800}$

$UCE = \dfrac{EGC}{aTO \times ToP} = \dfrac{N1{,}843{,}587{,}800}{2160 \times 2222}$

$= N384.12\ Naira/KWh$

- ***Cost Model of Proposed Diesel Generators based on Zoning***

Theoretical generation cost per annum is a cumulative sum of the total cost of procurement of the generating sets and the function of the proposed annual cost of fuelling and annual cost of maintenance. This is computed via postulation from the empirical generation cost per annum.

$$TGC = \sum [TCP, f(aCF_p, aCM_p)] \quad (2)$$

Where,

$TCP = \sum_{i=5}^{n} UCP_i$

$aCF_p = 12(mCF_p)$

$mCF_p = 20 \sum_{i=5}^{n} CFp_i$

$aCM_p = f(aCRS_p, aCPR_p, aMC_p)$

$ToP = 0.8 \times 1850KVA = 1480KW$

$aTO = 9hrs \times 20days \times 12months = 2160hrs$

The procurement cost all proposed generators were considered with the current pricing as shown in Table 6.

Table 6: Procurement cost of Zoned Generators.

Rating (KVA)	*Number*	*Unit price (N)*	*Total price (N)*
500	3	93,580,300	280,740,900
250	1	25,000,000	25,000,000
100	1	20,000,000	20,000,000
			325,740,900

Currently a litre of diesel is sold at N1250 and the fuelling cost of the 5 proposed zoned diesel generators was postulated and computed as shown in Table 6. The computation obtained reveal that about 28,800 litres of diesel will be consumed monthly.

Table 7: Cost of Fuelling

Rating (KVA)	*Number (Functional)*	*Consumption per month (Litres)*	*Monthly Cost of fuelling (N)*	*Annual Cost of fuelling (N)*
500	3	19200	24000000	288000000
250	1	4800	6000000	72000000
100	1	4800	6000000	72000000
		28800	**36,000,000**	**432,000,000**

The interpolation of the basic and operational information of the zoned generators showed that **N28,715,000** will be spent on cost of maintenance per annum.

$TGC = 325{,}740{,}900 + 432{,}000{,}000 + 28{,}715{,}000$

$= \boldsymbol{N786{,}455{,}900}$

$UCE = \dfrac{TGC}{aTO \times ToP} = \dfrac{N786{,}455{,}900}{2160 \times 1480}$

$= \boldsymbol{N246.01}\ Naira/KWh$

- ***Cost Model of proposed 5.56MW photovoltaic power plant***

Due to the unavailability of the inverter recommended by Iwuamadi, Anyaehie and Nwadike (2022), *600KVA/480Vdc, 3phase 0.9pf* Xantra Online Inverter systems were used in this study.

$Total\ Battery\ Capacity = 109341.26Ah$

$Battery\ Capacity\ per\ plant\ inverter = \dfrac{109341.26}{11}$

$= 9940Ah$

$Recommended\ battery\ type: LPBF\ 17.5KWh\ 480V\ 350$

$Number\ of\ batteries\ per\ plant\ inverter = \dfrac{9940}{350}$

$= 28.5 \approx 29$

$The\ 29\ batteries\ will\ be\ stacked\ in\ parallel\ to\ generate$ 4.872MWh at 480Vdc, 10150Ah.

$\therefore Total\ number\ of\ plant\ batteries = 29 \times 11$

$= 319\ batteries$

$The\ recommended\ MPPT\ controller:$

$480Vdc, 200A, 96KW\ Controller; Max.\ PV\ voltage\ 600 - 750V;$

$we\ chose\ 725.4V$

$Peak\ watt\ rating\ of\ the\ PV\ modules\ per\ plant\ inverter$

$= \dfrac{8462.45KW}{11} = 769.31KW$

$As\ recommended, 315W\ CS6K—315MS\ (IEC1000)$ $polycrystalline\ PV\ module$ is chosen.

It is derived from calculations that the PV modules will be arranged 18 pieces in series and 107 parallel arrays respectively.

$Number\ of\ PV\ modules\ per\ plant\ inverter = 1926$

$$Number\ of\ MPPT\ controllers per\ plant\ inverter = \frac{769.31KW}{96KW} = 8$$
$$Total\ Number\ of\ PV\ modules = 1926 \times 11 = \mathbf{21186}$$
$$Total\ Number\ of MPPT\ controllers = 8 \times 11 = \mathbf{88}$$

From technical inspection, a total of 4200m length of 150mm armored cable interconnecting the MPPT controllers, battery banks and inverters in the solar grid according to the zoning design. The budget estimate of 90mm armored cable, protectives devices, and accessories is estimated at N45,000,000.

Description	Number	Unit Price (N)	Cost Price (N)
$480V\ 350Ah\ LiFePO_4\ Solar\ battery$	319	4,836,000	1,542,684,000
$480Vdc, 200A, 96KW\ MPPT\ Controller$	88	5,414,900	476,511,200
$315W\ CS6K—315MS\ (IEC1000)\ poly\ PV$	21186	97,000	2,055,042,000
$600KVA/480V/3phase\ Xantra\ Online\ Inverter$	11	60,000,000	660,000,000
150mm armoured cable	4200	110,000	462,000,000
90mm Cables and accessories	Worth	45,000,000	45,000,000
Installation cost	Worth	40,000,000	40,000,000
			5,281,237,200

$$ToP = 4.872MWh \times 11 = 53592KWh$$
$$aTO = 9hrs \times 20days \times 12months = 2160hrs$$
$$UCE = \frac{TGC}{aTO \times ToP} = \frac{N5{,}281{,}237{,}200}{2160 \times 53592} = \boldsymbol{N45.62}\ Naira/KWh$$

Discussion

The results of the comparative cost analysis conducted for the electricity generation at the Federal Polytechnic Nekede reveal important insights into the economic implications of relying on diesel generators versus transitioning to photovoltaic (PV) solar power.

The empirical generation cost (EGC) from existing diesel generators was calculated to be approximately N384.12 per kWh. This high cost can largely be attributed to several factors, including the fluctuating prices of diesel fuel, high maintenance and operational costs, and inefficiencies resulting from the non-optimal loading of generators. The data indicates that the institution operates a significant number of diesel generators, incurring a cumulative annual cost of approximately N1.843 billion. This reveals a substantial financial burden on the institution, which could otherwise be allocated to educational resources and facilities.

The theoretical generation cost (TGC) from the proposed zoning arrangement of generators is estimated at N246.01 per kWh. This strategy aims to optimize the operation and reduce the number of active generators, leading to a reduced fuel consumption and operational costs. Although this proposed zoning arrangement demonstrates a significant cost reduction compared to the empirical costs, it still does not compete with the cost-effectiveness of renewable energy sources.

The standout result is the proposed 5.56 MW solar PV power plant with a unit cost of electricity of N45.62 per kWh. This indicates a remarkable reduction in electricity expenses when compared with both the EGC and TGC from the diesel generators. The initial investment for the solar PV system is substantial (approximately N5.28 billion); however, considering its operational and maintenance costs are generally lower and the absence of fuel costs, the return on investment is projected to yield significant savings over time. Beyond financial aspects, the transition to solar energy addresses environmental concerns associated with diesel generators, particularly air pollution and carbon emissions. Given the global push towards sustainable practices, adopting solar PV technology not only aligns with environmental sustainability goals but also enhances the institution's image as a responsible and forward-thinking establishment.

The findings suggest that a strategic investment in solar energy infrastructure can lead to long-term financial benefits and energy security for the Federal Polytechnic Nekede. With the decreasing trends in solar PV installation costs and the increasing efficiency of equipment, there may be further cost reductions in the future. Additionally, adopting renewable energy solutions can assist in mitigating the electricity poverty challenges facing Nigeria, thus contributing to broader socio-economic development objectives.

Strategic Recommendations

Based on the findings of this study, it is recommended that Federal Polytechnic Nekede explore financing options, such as public-private partnerships and government incentives, to facilitate the transition to solar energy. Future research could extend to a more detailed analysis of the operational and grid-integration challenges associated with solar PV deployment, taking into account storage solutions and energy management systems.

In conclusion, the comparative analysis clearly indicates the financial and environmental advantages of investing in solar photovoltaic systems over traditional diesel generators. This transition is essential not only for reducing operational costs but also for aligning the institution with global sustainability efforts and improving its power reliability.

Conclusion

The comparative cost analysis of electricity generation from diesel generators and photovoltaic systems undertaken in this research at the Federal Polytechnic Nekede, Owerri, underscores the pressing need for a shift toward sustainable energy solutions to address the inherent inefficiencies and high costs of current electricity sources. The results indicate that while existing diesel generators incur substantial operational expenses, a restructured zoned generator approach provides a moderate cost relief. However, the most compelling outcome is the substantial cost savings achievable through the adoption of a 5.56 MW solar photovoltaic power plant, which offers a dramatically reduced cost of N45.62 per kWh compared to N384.12 and N246.01 per kWh for diesel generators. Beyond economic considerations, this transition to PV technology presents an environmentally friendly alternative that aligns with global sustainability goals. Hence, it is recommended that Federal Polytechnic Nekede, along with other institutions facing similar challenges, pursues investment in solar energy infrastructure as a critical step toward sustainable energy independence, cost reduction, and improved service delivery. This research contributes valuable insights into the potential for renewable energy to alleviate electricity poverty in Nigeria, reinforcing the need for policy support and investment in renewable energy projects nationwide.

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