LUKMAN AHMED OMEIZA
UKASHAT MAMUDU
KATERYNA KOZAK
SALAWUDEEN AHMED TIJANI
and
AIKHONOMU OSAYEMEN DANIEL

Minimizing the cost of energy consumption for public institutions in Nigeria

Energy and humanity are superimposed. Its importance to mankind and indispensable nature to the world cannot be overemphasized. Public institutions need energy to carry-out their daily activities. The increase in the demand for energy in public institutions can be traced to advancement in technology. Thus, resulted to a sharp increase in the energy consumption, thereby increasing the energy monthly utility bill astronomically. This has put pressure on public institutions in Nigeria, as most of them are heavily indebted to energy companies.

Due to constant electric power failure in Nigeria, public institutions rely heavily on diesel generators to argument their daily energy need. Cost minimization and a sustainable clean energy has become a priority for the managers of our public institutions. This study was carried out to establish the exact amount of energy consumption at the Federal Polytechnic Bida, Nigeria, and fashion outways of reducing the cost burden for the institution.

The study was achieved through the installation of "Efergy meter" to understudy the energy audit of the institution. Base on the result obtained, the exact amount of energy consumption were established. Solar photovoltaic (PV) system was considered clean and cost-effective options for our public institutions on the long term.

Keywords: Efergy meter; public institution; Federal Polytechnic Bida; diesel generator; renewable energy; solar PV-system.

1.0 Introduction

Energy is key to socio-economic development of all nations around the world [1, 2]. Public institutions, such as polytechnics, universities and all other forms of tertiary institutions of learning needs constant energy supply to meet their daily work demands. Laboratories, research centres, hostels and administrative buildings in our public institutions cannot survive a single day without adequate supply of energy. Therefore, it is important to find a sustainable, clean and cost-effective way to keep our public institution running, without too much cost burden and to sensure constant energy supply to critical infrastructures.

Due to the current COVID-19 pandemic, institutions around the world has switched over to virtual learning platforms, thereby constant energy supply for critical infrastructures are on the high demands. It will be a total disaster if the ICT unit goes off for hours during this pandemic era, such units need constant energy supply to keep knowledge and information dissemination alive in our public institutions. Due to the surge in energy demand during this COVID-19 pandemic, there is also a sharp increase in monthly energy bills, thereby plugging so many public institutions in Africa into heavy debt burden with energy supplying companies.

Electrical energy are the most sorted after in our public institutions and they can be produced from both sustainable (justifiable sources) and non-sustainable (non-justifiable sources) [3-5]. Most African countries have inadequate energy infrastructure, with electrical energy generation in Africa standing partly at four per cent (4%) of the world electric energy consumption [4]. The electrical energy demand in Nigeria cannot be met wholly by the nation grid, this is due to insufficient electrical energy generation, resulting from poor infrastructure [5]. Nigeria only generates fifteen per cent (15%) of its 31000MW energy demands as at 2015 [6]. This has serious adverse impact on the socio-economic life of the Nigerian populace.

The public institutions, a major consumers of electrical energy have been forced to rely on diesel generators to meet up with their demand for electrical energy supply in Nigeria. Most public institutions in Nigeria spends millions of naira monthly to buy fuel (diesel) for their generators [7, 8]. This has a huge effect on the revenue generation of this institutions. Their ability to invest in research and capital development is seriously hampered. Infrastructures are left to

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Messrs. Lukman Ahmed Omeiza, Department of Electrical/Electronic Engineering, Federal Polytechnic Bida, Niger State, Ukashat Mamudu, Department of Mechanical Engineering, National Metallurgical Developmental Centre, Jos, Nigeria, Kateryna Kozak, Department of Electrical Engineering, Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine, Salawudeen Ahmed Tijani, Department of Electrical Engineering, University of Jos, Plateau State, Nigeria and Aikhonomu Osayemen Daniel, Department of Control Engineering, Concordia University, Montreal, Canada. e-mail: lukahmed378@gmail.com / ukashatmamudu87@yahoo.com / kozakateryna@gmail.com / elteejayy@hotmail.com / danielose2009@yahoo.com

decay, because public institutions cannot afford to renovate them, as paucity of funds lingers in our public institutions. Nigeria for examples has more than eight millions of its students studying outside the shores of the country, due to the poor nature of our tertiary institutions infrastructure [9]. Money that could have been freed to develop the polytechnics, universities and other tertiary institutions are paid to energy companies as monthly utility bills, this are not inclusive of money spent on daily operation of generators and maintenance activities. The problem of regular electric power outage and its epileptic nature in Nigeria, has made public institutions to depend on six to seven hours of their electric energy need squarely on diesel generators [10]. Thereby, adding to the cost burden of providing uninterrupted power supply in running the daily energy need of our public institutions. Renewable energy systems are regarded to be cost-efficient, reliable and free of toxic gas emission and are therefore regarded as environmental friendly [9]. The study focused more on solar energy analysis, its cost-effectiveness in supplying alternative and uninterrupted power supply to the Federal Polytechnic Bida, Nigeria.

The wildfire in Siberia, Algeria and some parts of Europe call for a serious concern. Global warming is real and we cannot afford to continuous release of toxic gases to the atmosphere, time to stop atmospheric pollution is now. The need to shunt diesel generators and all other forms of non-renewable energy is fast approaching if we must reach the United Nation goal of stopping further depletion of the ozone layer by 2030 [11]. There is an urgent need to completely remove diesel generators from our public institutions, their hazardous effect should not be entertain anywhere near our learning environment.

In study [12], it was proved that efficient use of natural light can drastically lower the cost of energy consumption in office buildings. This is correct if only lighting systems are the only major consumer of energy in the office buildings. But given the fact that there are various other energy consuming devices, such as air conditioners, printers, laptops and many heavy laboratories equipment, a system must be derived to ensure this various energy consuming devices also have a fair share of their required energy from the natural source light (Sun). This is where the designing of a photovoltaic solar system becomes a huge interest, since they have the ability to trap sunlight and convert it electrical energy, which is clean and sustainable [13].

This study, focused on the electrical energy demand and alternative sources for meeting up the energy requirement of public Institutions in Nigeria, and this study was achieved using the Federal Polytechnic Bida, Nigeria as a feasibility study. A well designed energy analysis will be the first option to a cost-effective solution to public institutions. This will serve as alternative solution to the rapidly growing energy demand of the new-era, which will lead to a more reliable and cost-effective solutions. The heavy debt burden of supplying energy to our tertiary and public institution of learning, will have been reduced greatly. This will in turn free more funds for capital, infrastructure and research development. A conducive and environmental friendly scenario can only be achieved if we deal away with all sources of environmental pollution [14].

2.0 Materials and methods

Essentials data were collected through site survey of all four vital buildings in the polytechnic. This includes the admin block, business centre hall, security outpost and student hostel. An "efergy meter", was installed to carry-out the energy audit of the buildings, as accurate energy audit is the first step in a reliable energy design system. In the study [14], audit of energy can be categorized into three; these are walk-through, investment grade and general assessment, they all depends on the holistic nature and purview of the audit. The efergy meter has three major component, which are the transmitter, router and a meter [15]. The efergy transmitter consist of three magnetic probes, which is connected to the most central load lines of the transfer switch. The efergy meter has a working range of five seconds (5s), ten seconds (10s) and fifteen seconds (15s) [16]. These are the time range in which load and energy data are sent to efergy meter.

The data received by each efergy meter are in turn transmitted online, with the help of the router and can be tracked in real-time on the dashboard of each Efergy Meter

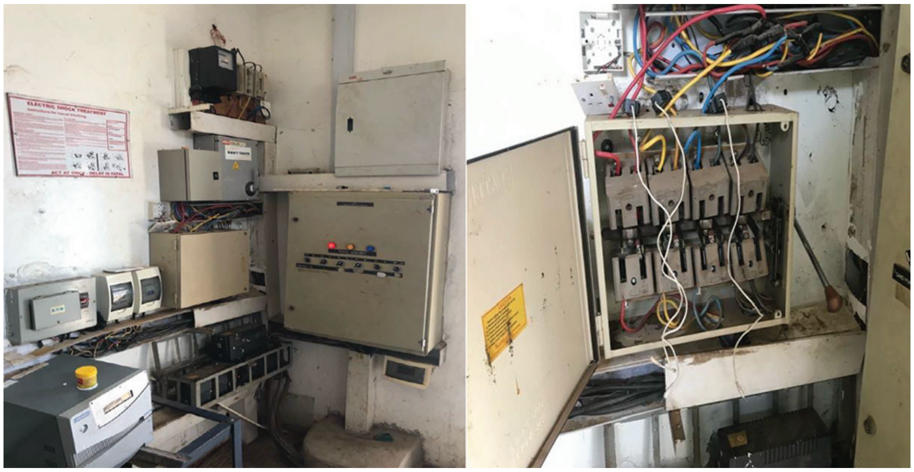

Fig.1: Pictorial view of the efergy with three magnetic probe connected to the central load lines of the transfer switch in the admin block

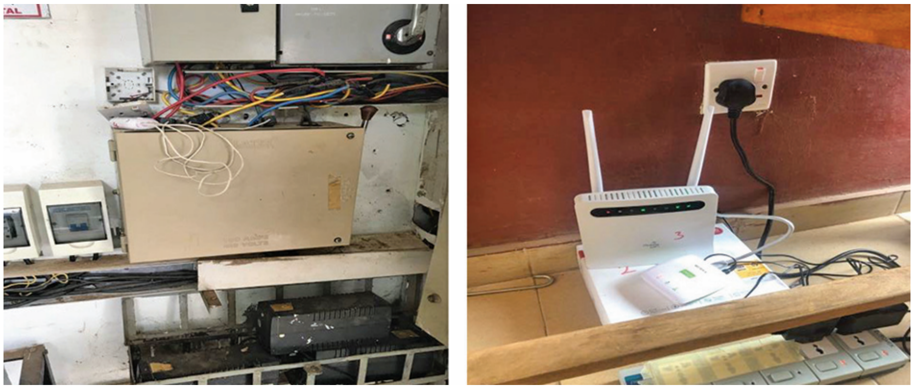

Fig.2: Pictorial view of the efergy transmitter connected to the transfer switch and the efergy router connected to meter in the admin block

via the website [17]. This data are then collated to help us understand the energy need of each buildings. The energy profile of each buildings are accurately gotten and this will help us with the futuristic design plan. Several other studies, have been performed as regards energy audit and load analysis, most of the methods put forward did not offer solutions to energy consumed by transmission lines [18]. Thereby, leading to inaccurate design analysis and planning for office building located inside public institutions. In most of this studies a twenty five per cent (25%) increase is added to the final value of energy consumption, this were meant to take care of future increase in energy demand and any inaccuracy that might have been associated with the methodology applied [19, 20]. With the help of the efergy meter, inaccuracy of load profiling is reduced to near zero, any twenty five per cent increase to the final value of energy data, will only help in taking care of future increase in energy requirement of the buildings. Time saving is also of critical importance, the numbers of days and personnel that will have been required to perform energy audit has also been reduced, as the efergy meter has the capacity to perform energy audit faster and accurately with less personnel involved, cost of labour will have reduced drastically. The effectiveness of the efergy meter in energy audit for energy designing system has never been tested, the efergy were only previously use to determine unit cost of energy consumption for solar companies. Haven knows the peak load at different interval it is easy to then determine the average peak load of energy consumption per, this will be great help to our study. The accuracy of the efergy are not in doubt, since they have been put to use to find unit cost of solar energy consumption, all we need is to track the different peak load over the six month duration to be able to accurately decide the maximum amount of energy consumption per day.

The efergy meter was installed in February 2021 for a period of six months in the four main buildings at the Federal Polytechnic Bida, they were then uninstalled in August 2021. This was to ensure that the different peak load were recorded in other to ensure effective energy design system for the institution. Since the polytechnic runs two smester per year, the efergy meter was installed for the whole duration of the first semester, as expected the energy consumption will be minimum during holidays, so this was captured in the six months duration of the efergy datasheet.

3.0 Load analysis

Analyzing the result of the energy audit is the first essential step in achieving a comprehensive energy management design [21-24]. This will help in modelling a cost-effective plan for any futuristic energy project. Based on the data obtained from the efergy meter, a cost-effective energy supply system will be built.

The Table 1 illustrates the peak load obtained for the four different buildings at the Federal Polytechnic Bida, Nigeria.

The official working hours in Nigeria is from 8AM to 5PM, making a total of nine hours per day. In this study we will be making use of ten work hour for each day, covering a period of five working days for each week.

This will give us a total of 261 working days per year, and taking a futuristic plan of five years design into consideration, we will have a total of 1,305 working days, with all necessary public holidays in Nigeria taking into account. The Table 2 shows the total energy consumption per day in the four main buildings at the Federal Polytechnic Bida, with an average of ten working hours.

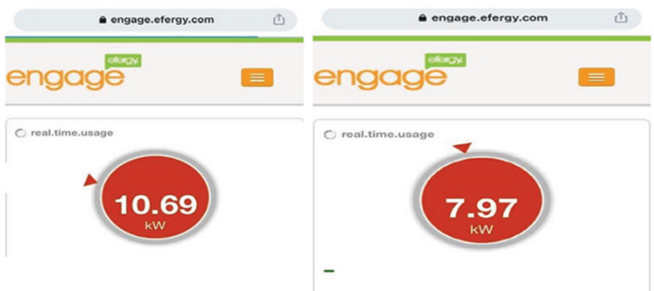

Fig.3: Dashboard real-time reading of the efergy meter [16]

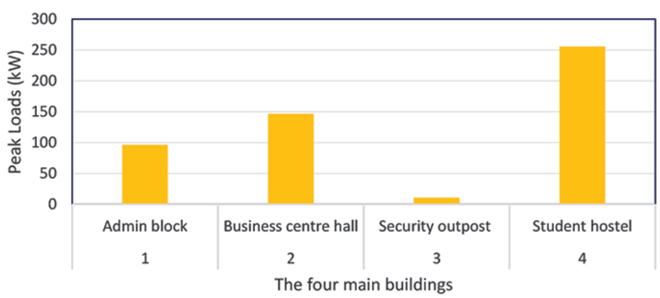

Fig.4: Load analysis of the four main buildings

Table 1: The result of the peak load obtained for the four main buildings at the federal Polytechnic Bida

	Description	Peak load (KW)
1	Admin block	96.5
2	Business Centre hall	146.8
3	Security outpost	10.9
4	Student hostel	255.6
5	Total	509.8

Table 2: The total energy consumption in each building

	Description	Peak load (kW)	Working hours (h)	Energy consumption (kWh)
1	Admin Block	96.5	10	965
2	Business centre hall	146.8	10	1,468
3	Security outpost	10.9	10	109
4	Student hostel	255.6	10	2,556
5	Total	509.8		5,098

3.1 Estimating unit cost of renewable source energy

According to the study [22, 23], the unit cost of supplying electrical energy through a renewable source can be found using thermos-economic equation. Finding the unit-cost of supplying electrical energy from non-depletable sources (renewable) and depletabe sources (generators) can be determined by the cost balancing equation.

$$C_f E_z^p + \Sigma C_1 = C_w E_z^j \quad ... (1)$$

C_f = per unit cost of fuel

E^p_z = Consumption rate of fuel energy

C_1 = Component of capital cost

E_z^j = Electrical energy generation rate.

$$\Sigma C_1 = C_w T_c E_z^w \quad ... (2)$$

$$Tc = \frac{\text{Electrical energy generatied annually by the energy system}}{\text{Annual capacity of the energy system}} \quad ... (3)$$

Tc (capacity factor) can then be replaced by factor of energy utilization of the system, this is shown in equation (4).

$$Up = \frac{\text{Annual total hours of operation}}{365*24} \quad ... (4)$$

3.2 Estimating the unit cost of electric energy generation by the national grid

Since the total energy consumed in the four main buildings is 5098kWh/day, the tariff for energy consumed in Nigeria is 35.35NGN/kWh; this is the amount set by the national energy regulation council (NERC) [25].

The estimated average total of daily energy consumption = Daily average total of energy consumed * Tariff [26] ... (5)

= 5098*35.35 = 180,214.3 NGN/day

Taking the futuristic plan of five years into consideration, assuming the Nigerian energy tariff for public users remain unchanged, then the energy cost for 1,305 work days will be;

Cost of energy for five years duration = 180,214.3*1,305 = 235,179,661.5 NGN.

3.3 Estimating the unit cost of diesel generator

Since the total load of the four buildings is known to be 509.8kW, we can determine the diesel generator capacity to use [25]. With a power factor 0.8, we can size the generator accordingly; apparent power (kVA) * Power factor (pf) = actual power (kW) ... (6)

$$\text{Apparent power} = \frac{\text{Actual power (kW)}}{\text{power factor (pf)}} \quad ... (7)$$

$$\text{Apparent power} = \frac{509.8}{0.8} = 637.25 \text{ kVA}$$

With respect to this study and analysis, an Olympian GEP660-1 with capacity 660kVA/528kW, 3-phase, 400-V, 50 Hz was chosen, with a maximum capacity of 660kVA and a fuel (diesel) consumption rate of eighty two litre per hour (82 litre/hour) and has a lube oil capacity of forty five litres [27, 28].

Purchase cost = 60,500,000 NGN

Installation cost = 500,000 NGN

Diesel buying price with annual inflation taken into account = 300.5 NGN/litre

Daily consumption of fuel (diesel) = 820 litres

Daily cost of fuel (diesel) = 82*10*300.5 = 246,410 NGN

Total extimated daily energy consumption = 5098 kWh/day

Hourly energy consumption for a ten-hour work day = 5098/10 = 509.8 kWh

Yearly maintenance cost = 800,000 NGN

Estimating all cost for a period of 5 years = 60,500,000 + 500,000 + (246,410*1,305) + (800,000*5) = 386,565,050 NGN

$$\text{Daily generator usage cost} = \frac{386,565,050}{1,305} = 296,218.8 \text{ NGN}$$

$$\text{Per unit cost} = \frac{\text{Daily cost of energy}}{\text{Total daily consumption kWh}}$$

$$= \frac{296,218.8}{5098} = 58.1 \text{ NGN/kWh}$$

3.4 Estimating the cost of setting up a photovoltaic solar energy system

A lot of study has been done on photovoltaic solar energy system, which has highlighted it to be more affordable and accessible to the common mass [29], [30]. The China government has spent billions of dollars in photovoltaic energy system design, making it more surplus to the global community, most neighborhood in China will be solar independent by the year 2030 [31]. This simply implies that monthly utility bill on electrical energy will come to an end for those community, since they do not rely on the national grid.

Solar energy system is a sustainable source of energy that makes use of solar-photovoltaic-cells (PVC) to trap sunlight energy and convert it into electrical energy [32-35]. The electrical energy gotten from it can be put to use immediately or stored in batteries to put to use when the need arises [36]. The solar energy system consists of the following major components; PV modules, charge controller, inverter, batteries, subsidiary energy sources and load devices [34]. For this study we are going to make use of the following design parameters:

Depth of discharge = 50%

Urated = Rated terminal DC voltage = 48V

Number of autonomy days = 1.5 Days

Battery amperage = 2,490 AH

Hop = Operation hours per day = 10 hours

I. Sizing of the battery

Estimated Wh capacity of the four buildings = Total energy consumption of the four building × Days of autonomy = 5098*1.5 = 7,647 kWh

Depth of discharge allowed = 50% (~0.5)

Loss factor of the battery = 0.9

Design kWh capacity = 7,647/(0.5* 0.9) = 16,993 kWh

Ampere-hour rating = 16,993/48 = 354 kAh or 354000 Ah

Number of batteries required = 354000/2490 = 142 (142-wet cells batteries)

II. Sizing of inverter

The inverter will be required to handle a maximum load capacity of 509.8kW, thus, nine of sixty kilowatt (60kW) inverters will be ideal for this study; this will be equivalent to a total of 540kW, which has a good safety margin.

III. Sizing of solar PV

Estimated total-watt-hours required per day for the four main building = 5098 kWh/day. Desired watt-hours required from the PV system = 5098*1.3

Generation factors for panels in Nigeria = 3.41

Estimated total watt-peak ratings = 5098*1.3/3.41 = 1,944 kWpeak PV power rating per module = 400 Wpeak

The number of solar panels required for the designing = 1944000/400 = 4860 panels.

Thus a total of 4860 panels of 400 Wpeak will be needed to supply the required amount of energy to the four main buildings.

IV. Sizing the charge controller

The rating of a charge controller is given by the equation (8);

Per string of solar charge controller = Isc*1.3 (Isc = all short-circuit current in the PV array) (8)

P_{max} = 400 Wpeak

V_{max} = 49.27 Volts (DC)

I_{max} = 8.12 Amps

Voc = 61.10 Volts (open circuit)

Isc = 8.62 Amps (short-circuit)

The minimum rating allowed on a single solar charge controller = (4860* 8.62)*1.3 = .54, 461 Amps

By using nine strings of PV modules per controller = (9*8.62)*1.3 = 100 Amps.

V. Cost analysis of acquiring all necessary components for the PV system

Evaluating the cost requirement of setting up of a PV system requires the thorough knowledge of the life expectancy of the PV-system. In the study of [37], a PV-system has an estimated average life-cycle of twenty five years. They are mostly sold with a limited product guarantee of ten years, this include workmanship and materials and twenty five years energy guarantee. The cost requirement for setting-up of a solar PV-system is tabulated in the Table 3, this includes all necessary components to carry out the PV-system project.

Purchase cost of various components and installation = 284,205,000 NGN

Yearly maintenance cost = 30,000 Naira

Five years futuristic plan cost = 284,205,000+(30,000×5) = 284,355,000 NGN

$$\text{PV system daily cost of usage} = \frac{284355000}{1,305}$$

$$= 217,896.55 \text{ NGN}$$

PV System per unit usage cost =

$$\frac{\textit{Daily cost of energy}}{\textit{Total energy consumption}} = \frac{17896.55}{5098} = 42.7 \text{ NGN/kWh}$$

4. Results

With the results of the study an informed decision can be taken on the best way forward to reduce the total cost of energy consumption for our public institutions in Nigeria. This will help save funds on the long term for the management of the Federal Polytechnic Bida, Nigeria, which can be invested in critical infrastructure development. The result obtained from the study are tabulated in Table 4.

Table 3: Estimating the cost of setting up PV system with all necessary components

	Components	Design-type	Quantity	Estimated rate	Cost (NGN)
1	Cables and accessories			300,000	300,000
2	Batteries	Deep-cycle	142	550,000	78,100,000
3	Inverter	60kW	9	600,000	5,400,000
4	Charge controller	100A, 48V	545	40,000	21,800,000
5	Solar PV panels	400W, 48V	4860	35,000	170,100,000
6	Combiner boxes		545	15,000	8,175,000
7	Battery rack		1	100,000	100,000
8	Panel rack		1	80,000	80,000
9	Breaker		1	60,000	60,000
10	Distribution unit		1	40,000	40,000
11	Transfer switch		1	50,000	50,000
12	Total cost (NGN)	284,205,000			

Table 4: The estimated cost analysis for the three energy sources

	Description	Daily cost (NGN)	Unit cost (NGN)	Total cost (NGN)
1	PV-System	217,896.55	42.7	284,355,000
2	Diesel Generator	296,218.80	58.1	386,565,050
3	Nation Grid	180,214.30	35.35	235,179,661.50

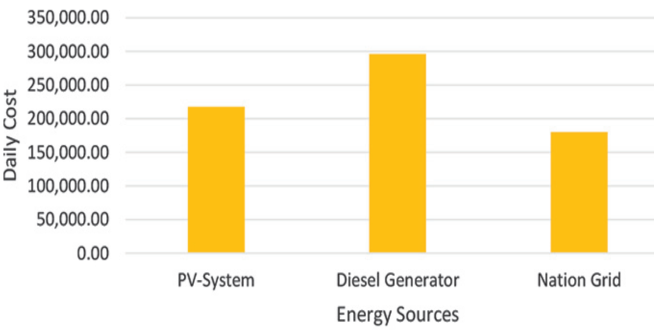

Fig.5: Graph showing daily cost of energy consumption from three different sources

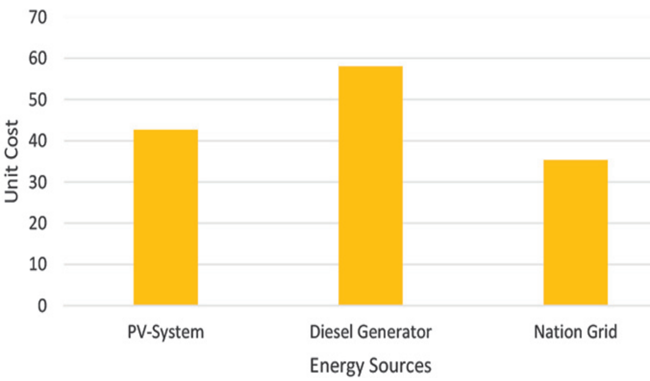

Fig.6: Graph showing unit cost of energy consumption from three different sources

The cost trend of energy consumption for the three possible options are then illustrated in Fig.5, 6 and 7.

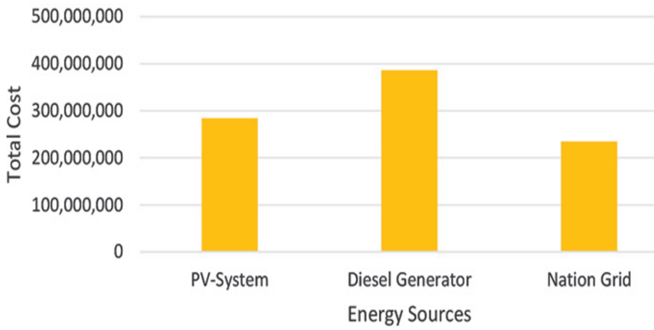

Fig.7: Graph showing total cost of energy consumption for three sources over a period of five years

5.0 Discussion

This study was dedicated to finding possible ways of reducing the cost of energy consumptions in public institutions here in Nigeria. The rising debt profile of our public institutions has become worrisome especially to energy companies, so there is the urgent need to find alternative and cost-effective ways of supplying energy to our public institutions. In the study [36], [37], much was dedicated to physical site survey of public offices, inaccurate load profile has become a serious concern to energy auditors. This has an adverse effect on the designing of an alternative source of energy to our public institutions, as much approximation and estimation are made. Time constraint is also a major headache for the modern days energy auditors [38], as plugging each load consumer to a watt-meter in a public office that has more than a dozen energy consuming equipment can be tasking. Energy auditor’s first major challenge is knowing the total load profile of our various institutions, this will help them evaluate the energy consumption requirement of each institution.

With the efergy meter, accurate load profiling of our public institutions can easily been found. This ensure that accurate designing of alternative, clean and cost-effective energy source is fixable. The management of our public institutions will be able to make an informed decision on the long term approach for ensuring continuous and uninterrupted supply energy to their various institutions with running into a serious debt burden.

6.0 Conclusion

The study was able to fashion out ways of which the cost of supplying energy to the Federal Polytechnic Bida, can be reduced. Our first approach was to select four main buildings, which are of utmost importance to the institution, an efergy meter was installed in the four main buildings for a period of six months, which covers the entire first semester of the institution and two months of holidays. The load profiles of the four main buildings were found, the daily energy consumption for a period of ten working hours were then calculated and result is tabulated in Table 1.

Based on the result of energy consumption for the four main buildings at the Federal Polytechnic Bida, Nigeria, it was discovered that the polytechnic will need an estimated NGN386, 565,050 to continue running there diesel generator for a period of five years. This source of energy is not clean and could lead to environmental hazard due to the continuous emission of carbon dioxide. It was advised that the diesel generator source should be replaced with solar PV-system, though the start-up cost might be a bit worrisome, but even at that, the start-up cost and maintenance cost of 284,355,000 NGN for a period of five years is still more economical than that of diesel generator within the same period study. It is also recommended that the national grid should serve as a backup for the solar PV-system, in case of any emergency maintenance of PV-system. Rationing between national grid and solar PV-system is also recommended, since this two sources are economical, clean and sustainable. A total sum of 102,210,050 NGN will be saved within five years, if the diesel generator source is completely replaced with PV-system, thereby freeing up fund for the much needed critical sectors within the public institution.

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Contributions

All the authors contributed immensely to the study.

Declaration of Competing Interest

The authors declare no conflict of interest.

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