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Economic Analyses of Integrating Solar Inverter into the Existing Energy Systems in Nigerian Healthcare Centers

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Authors' contributions

This work was carried out in collaboration between both authors. Author MAB designed the study, wrote the protocol, and wrote the draft of the manuscript. Author OOE performed the analyses and wrote the draft of the manuscript. Authors MAB and OOE managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Reliable electricity supply is crucial towards efficient healthcare delivery in a developing country like Nigeria, where national grid faces constant outages. Many healthcare centers depend on diesel generators, meaning high operational costs and environmental impacts. This study investigates the economic feasibility of integrating solar photovoltaic (PV) systems with existing energy infrastructure at a healthcare facility in Nigeria. Data were collected from a healthcare facility among others, and, using HOMER software; three different system configurations were simulated over a 25-year project lifetime, with focus on incorporating solar inverter system, alongside existing grid supply and generator. Results showed the optimal system configuration to

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be the one comprising of solar inverter system alongside the existing grid and diesel generator. This system has a significantly lower net present cost (NPC) of $382,263, compared to the base case scenario of $1,663,158, which relies totally on grid electricity and the diesel generator. The levelized cost of energy (LCOE) for the hybrid system is $0.139/kWh, also much lower than base case LCOE of $0.642/kWh. While initial investment cost for this system posed a challenge, the study demonstrated a payback period of approximately 4.8 years, with return on investment of 16%, and an internal rate of return (20.3%). The findings demonstrated the economic viability and potential benefits of integrating solar PV systems in the healthcare sector, as energy costs are lowered due to reduced billing and maintenance costs. This has significant potential for long-term cost savings, in addition to elimination of havoc-causing outrages. Furthermore, reduced dependence on diesel generator implies lowered greenhouse gases emission, which is beneficial to patients, staff and visitors. Government incentives or other financing mechanisms are potential solutions to high installation costs. This research is recommended for implementation in places like Nigeria, as it serves as a guide towards sustainable energy for improved healthcare delivery.

Keywords: Solar photovoltaic; healthcare; software; energy storage; renewable energy.

1. INTRODUCTION

Sustainable growth necessitates that energy supply be affordable and consistent [1]. Nigeria’s healthcare system is faced with a number of challenges, first of which is lack of reliable power supply [2]. Unstable and inadequate electricity supply in Nigeria makes the problems currently experienced by healthcare facilities worse due to interruptions of vital medical services which jeopardize patient care, in addition to making storage of vaccinations and prescription drugs very difficult [3,4]. This often hinders developments and causes loss of lives in extreme situations. Most health-care centers often fall back to diesel generators, whose high cost of maintenance weighs down their already stretched budgets [5]. Addressing these energy challenges in the healthcare sector is crucial for ensuring sustainable healthcare delivery and achieving better health outcomes for the Nigerian population. Integrating solar PV together with energy supply from national grid may serve as one of the potential solutions to the energy challenge [6]. Solar energy is one of the most promising sources of renewable energy in Nigeria due to its apparent abundance. Solar generating potential of Nigeria is about 7.1Kw/m^2/day, featuring as one of the highest in Africa [7]. Energy radiated from the sun is about 3.8×10^{23} kW, which is 1.082 million tons of oil equivalent (mtoe) per day. This is about 4000 times the current daily crude oil production in Nigeria, and about 13,000 times the natural gas daily production, based on standard energy units [8]. Solar photovoltaic (PV) adoption in Nigeria has been steadily increasing in recent years, making it promising towards the actualisation of Nigeria’s Sustainable Development Goals, SDGs [9,10]. Solar inverters are responsible for converting Direct Current (DC) output produced by solar panels into Alternating Current (AC) electricity, making it compatible with the national grid or local networks [11]. The conversion process is essential for enabling the integration of solar energy into existing energy infrastructures, ensuring its usability for various applications [12]. The role of solar inverters is critical in enhancing operational and technical performances of solar power plants and stabilizing the output of solar power systems [13]. This capability for voltage conversion and stabilization not only enhances the efficiency of solar energy utilization, but also contributes to the overall stability and resilience of the electrical grid [14]. In the mid-80s, introduction of grid-connected PV systems led to further development of solar inverters alongside output and efficiency [15]. Technological advancement also facilitated the development of complex inverters, such as the Maximum Power Point Tracking, MPPT inverters [15]. Towards the end of last millennium (1990s), more economical PV systems for residential areas came to existence with the introduction of transformerless inverters [16]. Moreover, versatility of solar batteries led to the creation of hybrid inverters, which can control both solar power generation and battery storage, making homes and businesses more energy independent [17]. While solar energy has been the primary focus of this study, it is essential to reflect on the potential contributions of other renewable energy sources in Nigeria's energy transition. Research findings have investigated the prospects of biomass energy in Nigeria, particularly from agricultural residues and municipal solid waste [18]. By leveraging on Nigeria's abundant biomass resources, it was indicated that the country can make significant strides towards achieving its renewable energy targets, and, reducing heavy reliance on fossil fuels. In the context of Nigeria's energy sector, fossil fuels reign supreme, contributing over 80% of the national grid's electricity [19]. In spite of this heavy reliance on fossil fuel, out of a total population of about 162million people, up to 40% of these Nigerians do not have access to electricity [20]. Energy is of paramount importance, as it is widely useful in all aspects of human endeavour for technological advancements, and can exist in several forms [21,22]. In its own case, solar energy is sourced from arresting sun's radiant energy and afterwards converting it into heat and electricity, among others [22]. Solar PV systems hold significant importance in healthcare settings due to their potential to enhance energy efficiency, reduce operational costs, and improve access to healthcare services. Moreover, solar energy systems contribute to mitigating environmental pollution and reducing carbon emissions, thus promoting a healthier environment for patients and staff. Recent findings highlighted the positive impact of solar energy adoption in healthcare facilities, especially for sustainability in resource-limited settings [23]. Although investment decisions are affected by upfront costs, operating expenses and revenue, economic sustainability of energy storage integration is still being debated [24]. Therefore, thorough cost-benefit studies are necessary in order to evaluate the financial implications of energy storage projects to be able to advise investors, project developers and legislators. A recent study analyzed the cost-effectiveness of the grid-connected energy storage systems in mitigating peak demand and reducing consumer's electricity costs [25]. Furthermore, the importance of a holistic assessment involving financial viability and environmental benefits has been emphasized [26]. Several other researchers have made significant findings on solar systems integration. For instance, a recent study on economic analysis of integrating solar inverters in residential buildings demonstrated significant long-term savings and payback periods [27]. Another study that analyzed the economic viability of solar PV systems across different regions of Nigeria revealed significant regional disparities, with the northern regions demonstrating higher economic potential due to higher solar irradiance levels and relatively lower component costs compared to the southern regions [28]. Some authors have also stressed the need for a stable and consistent policy framework to provide the necessary regulatory certainty that will encourage long-term investments in solar energy infrastructure [29]. Moreover, in recent times, a hybrid of renewable energy systems, comprising of solar and wind was reviewed [30,31]. While a group of researchers investigated integrating solar energy with home micro grid [32], another set similarly looked at integrating solar photovoltaic energy systems for industrial and commercial power consumption [33]. As most studies analyze standalone solar PV systems, research directly exploring the economic feasibility of integrating solar with existing energy infrastructure systems in healthcare facilities is scarce. Moreover, grid electricity tariffs can differ considerably across Nigerian regions. Most researches do not always account for this regional variation, leading to potentially inaccurate economic assessments. More studies are needed that incorporate location-specific energy costs into the Cost-Benefit Analysis (CBA) for solar integration projects. Thus, this study was centered on providing useful insights for decision-makers in the public and private sectors, by evaluating the costs of purchasing, installing, and maintaining solar inverters alongside current energy infrastructure. It also evaluated potential savings derivable, when reliance on traditional energy sources and grid-supplied electricity become reduced. Therefore, the study was aimed at conducting an economic analysis which involved combining existing energy production and storage systems with solar inverters at a health care center. Hence, the objectives of this study include (i) Assessing the economic feasibility of integrating solar inverters into healthcare facilities in Nigeria by analyzing initial investment costs, operational expenses, and potential energy savings associated with solar energy adoption. (ii) Evaluating the technical feasibility of integrating solar inverters with existing energy systems in healthcare facilities, considering energy consumption patterns and backup power requirements. (iii) Investigating the potential economic benefits of solar inverter integration in healthcare facilities in Nigeria. In terms of justification, installing solar inverters alongside energy supply from national grid in medical centers will guarantee an improved supply of electricity for critical medical equipment, vaccine and drug refrigeration, emergency lighting, and life-saving medical supplies. Additionally, solar inverter integration has potential for lowering short- and long-term energy expenditures; providing a viable and affordable substitute for diesel generators, which are frequently utilized as backup power sources.

2. METHODOLOGY

The procedures for identifying, obtaining data and analysing collected data are as presented in this section. To start with, alongside the healthcare facility being studied, some of the equipment and materials used include: log book, solar resources data, costs record book, electricity bills due to national grid supply, records on diesel generator's maintenance and fueling.

2.1 Setting

This study was focused on a privately-owned healthcare facility in Ikeja, Lagos State, Nigeria.

2.2 Data Collection

Historical data on daily load consumption was collected at the facility. For this, the hourly load profile data for a 24-hour period was obtained, capturing the facility's energy demand at different times of the day. The quantitative data used were collected through primary and secondary methods. Collection of primary data was by means of a walk-through audit of the facility [34] to determine the energy consumption of the medical equipment and other devices therein.

Historical resource data, including the monthly averages of solar Global Horizontal Irradiance (GHI) and temperature data for the facility's location was acquired from government resources and solar resource data bases of the National Renewable Energy Laboratory

Table 1. Information Collectable from Energy Audits

S/n	Information generated	Definitions
1	Process flowchart	A diagram that shows the sequence of operation
2	Equipment schedule	The collation of every used equipment.
3	Load summary	This is a concise summary of total load of each equipment class used in the factory and also the total load as well as the number of all the appliances in factory, it gives a quick look at what the heavy-duty appliances are.
4	Load distribution chart	This is graphical representations of the load summary via pie chart. It shows the relationship between each equipment and their loads
5	Energy consumption chart	This is a bar chart and pie chart representation of the energy consumption pattern, it shows the relationship between each equipment class and their energy consumption
6	Load intensity chart	Sets of charts that determines what the load intensive space/room are in the factory, by comparing the amount of load in each space to the area of the space
7	Energy intensity chart	Sets of charts that determines what the energy intensive space/room are in the factory, by comparing the daily, weekly or monthly energy consumption of each space to the area of the space
8	Peak load profile	The peak load curve is a graphical representation of the load to time period relationship of peak load equipment (equipment connected for both short and long periods of time). It gives a snapshot of energy consumption per time period in a day of peak load Equipment.
9	Base load profile	The base load curve is a graphical representation of the load to time period relationship of base load equipment (equipment connected for a long period of time). It gives a snapshot of energy consumption per time period in a day for base load equipment
10	Load profile (Base and Peak Load)	Chart that compares the base load profile and peak load profile.

(Source: [34])

Database. Relevant technical specifications and cost information for various system components, such as solar PV panels, batteries, converters, and diesel generators, were collected through market research. The secondary data were obtained by assessing the facility documents and market research to gather information on equipment lifespan, costs of Solar PV components and assembly. Information on various solar PV components specifications was also obtained.

To accurately model and analyse the energy system integration, an understanding of the healthcare facility's energy consumption patterns was essential. Following the information available in Table 1, data were collected during the walk-through audit of the healthcare facility for energy consumption analysis.

The following steps were undertaken to conduct the energy consumption analysis:

1. **Load Profile Data Collection**

Historical hourly load profile data for a typical 24-hour period was collected from the healthcare facility. This data captured the fluctuations in energy demand throughout the day, allowing for the identification of peak demand periods and overall daily energy consumption patterns.

2. **Load Characterisation**

The collected load profile data was analyzed to determine key parameters such as:

- Average daily energy consumption (kWh)
- Peak daily load (kW)
- Minimum daily load (kW)
- Distinct peak demand periods

This characterization provided insights into the facility's energy requirements and informed the sizing and configuration of the integrated energy system components.

The interaction between the existing energy systems, storage systems, and the solar inverter system was also simulated using the HOMER pro software to assess how they can meet the facility's energy needs and optimize energy usage.

2.3 System Modeling

The studied health-care system was modeled by specifying the load profile of the facility, designing the configurations and motives of the system, and assessing the energy supply status and availability of the Solar PV systems. HOMER pro software was used to simulate the electricity generation potential of the solar inverter hybrid system under observation based on collected solar irradiance data and system specifications. For this study, three configurations were focused on in the course of the modelling.

2.4 Economic Analysis

Economic tools and models were used to investigate the financial viability of this study. Using the cost-benefit analysis (CBA) as a tool, the potential cost savings from reduced grid dependence and fuel costs were compared to the initial investment. Ongoing maintenance costs were also established. Carrying out a cost-benefit analysis involves a structured process of identifying, measuring, and comparing the projected costs and benefits of a project or intervention. The simulations were based over a period of twenty-five (25) years.

The procedure for economic analysis is as itemized below:

1. Defining the Project: This was defined as integration of solar PV systems into the existing energy infrastructure of the healthcare facility.
2. Identification of Costs and Benefits:
   Costs: A list of all anticipated costs associated with the project was made. This includes:
   Direct Costs: These are tangible expenses directly linked to the project.
   Indirect Costs: less obvious costs like infrastructure upgrades needed, or potential productivity losses during implementation.
   Benefits: The expected benefits of the intervention were identified.

3. Quantification of Costs and Benefits: Monetary value was assigned to both the costs and benefits where necessary. This allowed for a more direct comparison.
4. It might be challenging to assign a monetary value to some benefits like improved quality of life. In such cases, these limitations were acknowledged and qualitative descriptions were employed alongside the quantitative data.
5. Establishment of a time frame: This is the timeframe over which costs and benefits

are being considered. This is important because benefits may accrue over time, while some costs might be upfront. The simulation period was set at 25 years.

Cost-Benefit Analysis: This method became necessary in assigning a monetary value to both costs and benefits. Likewise, net benefit (benefits minus costs) was calculated to assess the overall economic viability of an intervention.

Other financial models were employed to perform calculations for: payback period, Internal Rate of Return (IRR), Net Present Cost (NPC), and Levelized Cost of Energy (LCOE).

1. $Cost\ Benefit\ Analysis\ (CBA) = \frac{\sum Present\ Value\ of\ Future\ Benefits}{\sum Present\ Value\ of\ Future\ Costs}$ (1)
2. $Internal\ Rate\ of\ Return\ (IRR) = r_a + \frac{NPV_a}{(NPV_a - NPV_b)}\ (r_b - r_a)$ (2)

Where:

$r_a = Lower\ discount\ rate\ chosen$
$r_b = Higher\ discount\ rate\ chosen$
$NPV_a = Net\ Present\ Value\ at\ r_a$
$NPV_b = Net\ Present\ Value\ at\ r_b$

3. $Net\ Present\ Cost\ (NPC) = \sum_{n=1}^{N} \frac{C_n}{(1+r)^n}$ (3)

Where:

$N = Total\ number\ of\ time\ periods$
$n = Time\ period$
$C_n = Net\ cash\ flow\ at\ time\ period$
$r = internal\ rate\ of\ return$

4. $Levelized\ Cost\ Of\ Energy\ (LCOE) = \frac{\sum \frac{(I_t + M_t + F_t)}{(1+r)^t}}{\sum \frac{E_t}{(1+r)^t}}$ (4)

Where:

$I_t = The\ initial\ cost\ of\ investment\ expenditure\ in\ the\ year\ t$
$M_t = Maintenance\ and\ operations\ expenditures\ in\ the\ year\ t$
$F_t = Fuel\ expenditures\ in\ the\ year\ t\ (If\ applicable)$
$E_t = The\ sum\ of\ all\ electricity\ generated\ in\ the\ year\ t$
$r = discount\ rate\ of\ the\ project$
$n = Life\ of\ the\ system$

5. **Payback Period**

a. Simple Payback Perio= (Initial Investment or Original Cost of the Asset)/(Cash Inflows) (6)
b. Discounted Payback Period= (Initial Investment)/(Discount Rate ×Annual Cash Flow) (7)

2.5 Limitations

The study may be limited by the availability of secondary data regarding energy usage, and requirements for medical equipment. Also, considering variables like weather, shadowing, and system deterioration over time, the analysis might not adequately account for potential variations in energy generation from solar panels.

3. RESULTS AND DISCUSSION

In this section is showcased the results obtained from appraising the economics of integrating solar inverter into existing energy system at an Ikeja-based healthcare facility.

3.1 Setting

Ikeja, Lagos, Nigeria (Fig. 1), which is the setting for this work, is located on geographical coordinates 6.6018° N, 3.3515° E [36].

3.2 Data Collection

Having carried out all the procedures as described under section 2.2 (walk-through audit), it was deduced that the healthcare facility installed both national electricity grid, with a 50 kV generator serving as power backup. Table 2, which gives details on the average hourly consumption of the facility for 24 hours, was obtained. From the information available in Table 2 (and the appendix), the average daily consumption of the healthcare facility is found to be 29.02 kW, while the total daily load (average) is 172.24 kW. The peak daily load is 12.33kW while the minimum daily load is 2.13kW. Also shown in Fig. 2 is the hourly load consumption trend.

This chart signifies an increase in load demand between 9am-12pm and 4pm-7pm, indicating that these are the periods the healthcare facility usually operates heavy equipment, thereby increasing the load demand.

Also obtained include the data (downloaded) detailing the Solar GHI and the temperature for every month of the year. Fig 3 shows the Solar GHI while Fig. 4 shows the temperature distribution.

Fig. 1. Map showing Ikeja, Lagos, Nigeria, the location of the healthcare facility
(Source: [35])

Table 2. Load profile of facility

Hour	Load (kW)
0 – 1	2.13
1 – 2	2.15
2 – 3	2.33
3 – 4	2.21
4 – 5	2.41
5 – 6	3.16
6 -7	5.12
7 – 8	7.32
8 – 9	8.11
9 – 10	12.32
10 – 11	12.21
11 – 12	12.33
12 – 13	8.23
13 – 14	8.34
14 – 15	8.14
15 – 16	8.46
16 – 17	9.04
17 – 18	12.02
18 – 19	12.32
19 – 20	12.13
20 – 21	9.47
21 – 22	10.43
22 – 23	9.16
23 – 24	5.02

From Fig. 4, it can be seen that the months of Feb, Mar, Apr, May, Nov and Dec have the highest radiation values, indicating that these are months wherein the Solar PV system can generate peak electricity. With August having the lowest radiation level, it means it is the month with the lowest solar energy potential. The Solar PV system model consists of a generic flat plate PV and 12V, 1kWh lead acid battery as storage.

The relevant technical specifications and cost information for the systems components, such as solar PV panels, batteries, converters, and diesel generators, collected through market research and secondary sources include: information on size, the cost of purchase, installation, operation, maintenance, and the useful life of the equipment. These are as presented in Table 3.

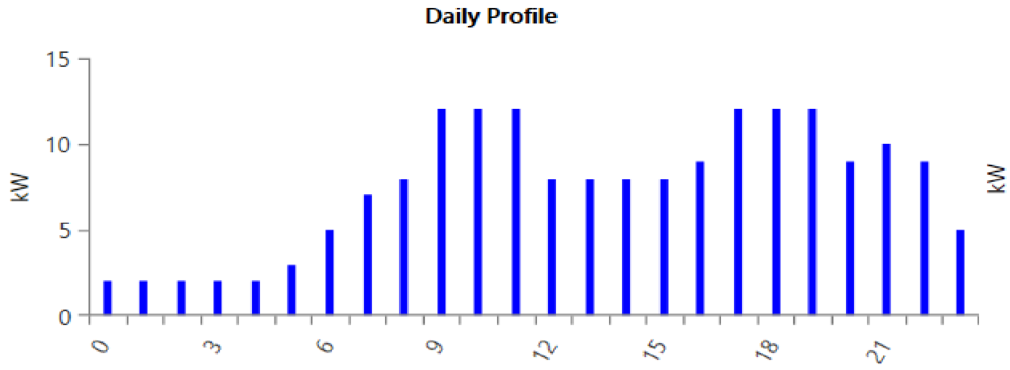

Fig. 2. Hourly load profile

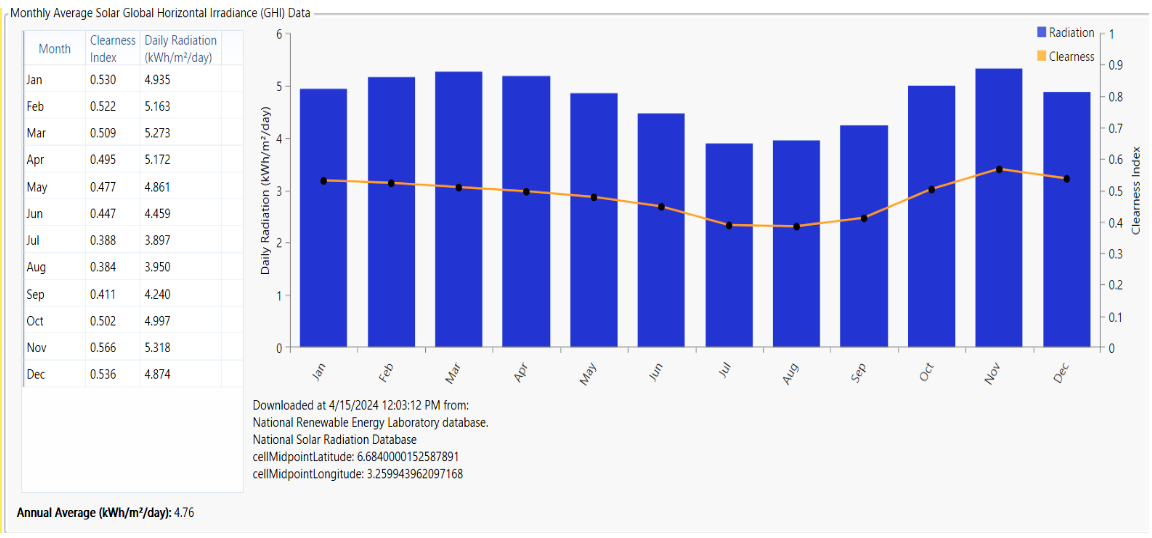

Fig. 3. Solar GHI for facility location
(Source: [37])

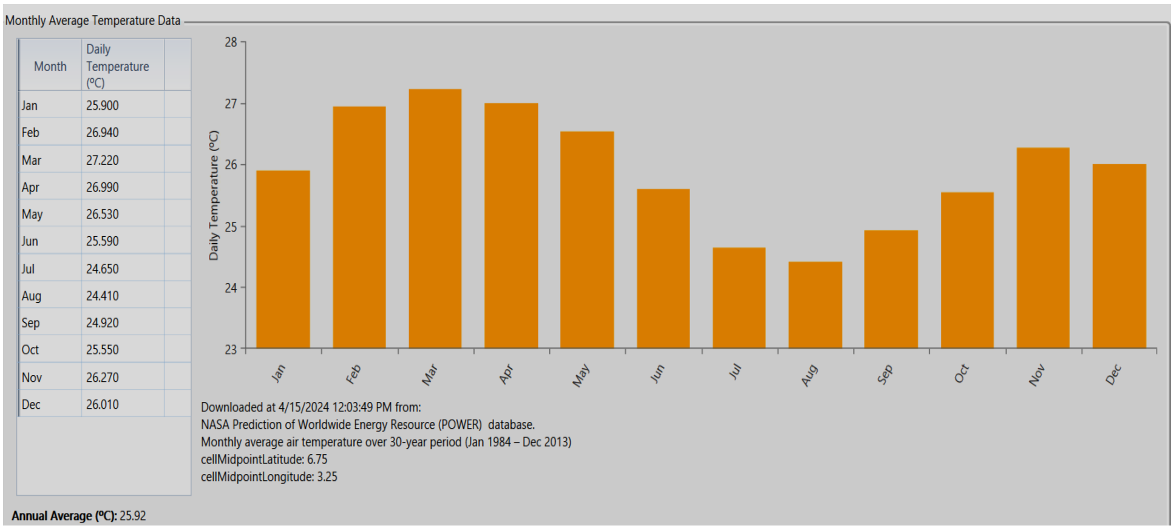

Fig. 4. Monthly average temperature data for facility location
(Source: [29])

Table 3. Cost of system components

Equipment	Size	Capital Costs ($)	Replacement Costs ($)	O & M costs ($)	Useful Life
Solar Panels	0.325 Kw	200	190	5.00	25 years
50 kVa Generator	50 kVa	0.00	3,000	1.50	15,000 hours
System Converter	10Kw	1,500	1,500	10	15 years
Battery	12v, 2.64kWh	200	200	2.00	18 years

The Base system already has a 50Kva generator as a backup source, bringing the capital cost of the generator to $0.

3.3 System Modelling

The three major energy sources put into consideration for in the study include: 1) Grid electricity, 2) A 50kva backup generator currently in use at the facility and 3) The proposed Solar PV system (comprising of 10kW system DC – AC converter (inverter); 7 of 12V, 210 Ah batteries; PVS series by BAE, Germany in block form; and 31 of 0.325kW each capacity generic flat plate PV panels). Fig. 5 shows a schematic model of the system detailing the converter, batteries, PV system Generator, and load profile.

The healthcare facility under study currently relies solely on Grid electricity, and with a 50Kva Generator as power backup. The facility combines these two sources to achieve a 24-hour power supply. Altogether, the three configurations considered in this study include: 1) Base configuration (GG – Grid electricity and Generator, currently in use in the healthcare center under consideration); 2) Test A configuration (SGG – Solar, Grid electricity and Generator) configuration; 3) Test B configuration (SG – Solar and Grid electricity).

3.4 Economic Analysis

Base system: With the existing energy system in the healthcare facility taken as the base configuration for the first simulation, over a period of 25 years, results, as shown in Fig. 6 were obtained. Table 4 also presents the details of the economic analysis of the system.

There was no capital cost incurred for the generator and grid, due to the fact that the system is already under usage. The diesel generator incurs majority of the costs as: replacement costs, operating and maintenance (O and M costs and high fueling cost. Over the length of the simulation (25 years), 27,447 liters of diesel fuel would have been consumed, bringing the total fueling cost to $1,113,849.16 with an average daily consumption of 75.2L. This poses a major problem for the base system.

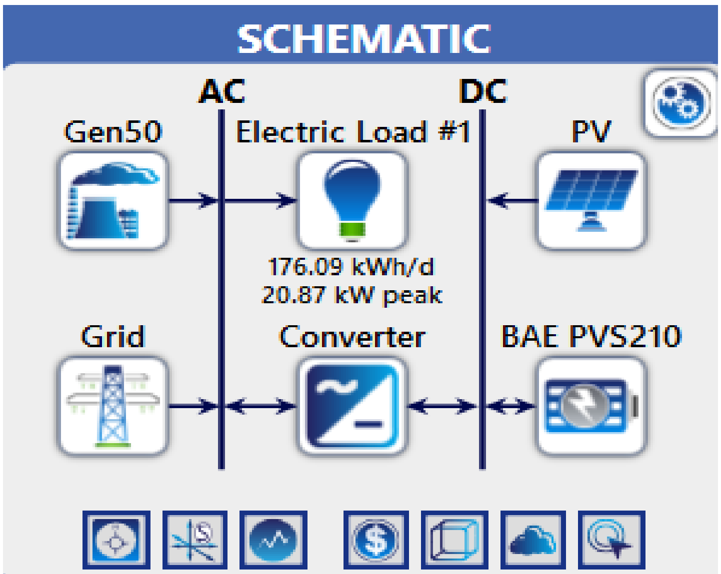

Fig. 5. Schematic model of the system

Table 4. Net present cost of Base (GG) system

Component	Capital ($)	Replacement ($)	O & M ($)	Fuel($)	Salvage ($)	Total ($)
50 kVa Capacity Generator	0.00	37,908.91	324,013.67	1,113,849.16	472.39	1,475,299.35
Grid	0.00	0.00	187,858.76	0.00	0.00	187,858.76
System	0.00	37,908.91	511,872.43	1,113,849.16	472.39	1,663,158.11

Table 5. Net present cost of Solar-Grid (SG) system

Component	Capital ($)	Replacement ($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
BAE PVS Block 12V 210	72,400.0	134,429.79	29,177.35	0.00	104,503.85	131,503.29
Grid	0.00	0.00	95.13	0.00		95.13
Generic Flatplate PV	138,927.94	0.00	139,970.62	0.00	0.00	278,898.56
System Converter	5,593.92	9,368.73	1,502.91	0.00	4,404.22	12,061.34
System	216,921.86	143,798.51	170,746	0.00	108,908.06	422,558.13

Table 6. Net present cost of (SGG) system

Component	Capital ($)	Replacement ($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
BAE PVS Block 12V 210	50,400.0	87,062.93	20,311.30	0.00	50,912.09	106,862.14
50Kva Capacity Generator	0.00	0.00	5,682.33	19,312.11	5,975.77	19,018.66
Grid	0.00	0.00	856.77	0.00		856.77
Generic Flatplate PV	123,678.45	0.00	124,606.68	0.00	0.00	248,285.14
System Converter	3,358.13	5,624.21	902.22	0.00	2,643.93	7240.63
System	177,436.58	92,687.13	152,359.31	19,312.11	59,531.79	382,263.33

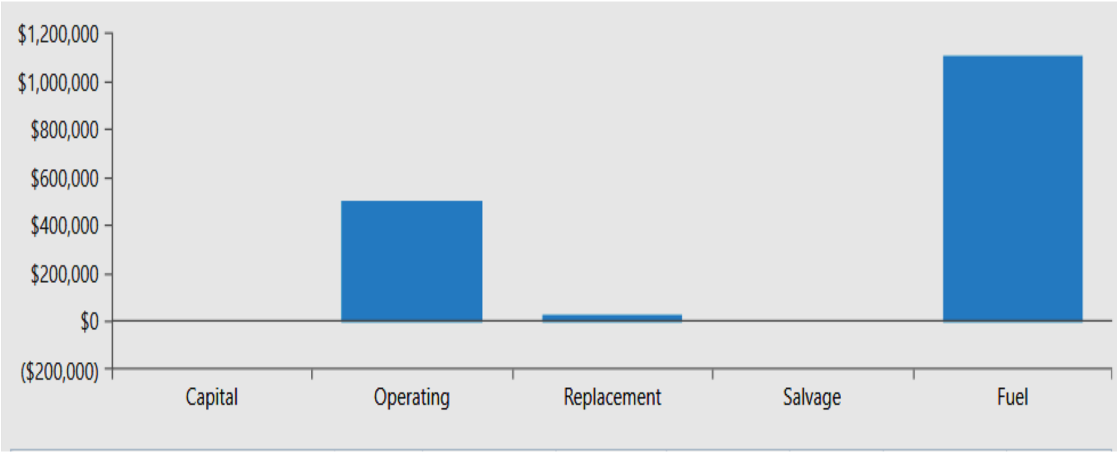

Fig. 6. Cost distribution for Base (GG) system over 25 years

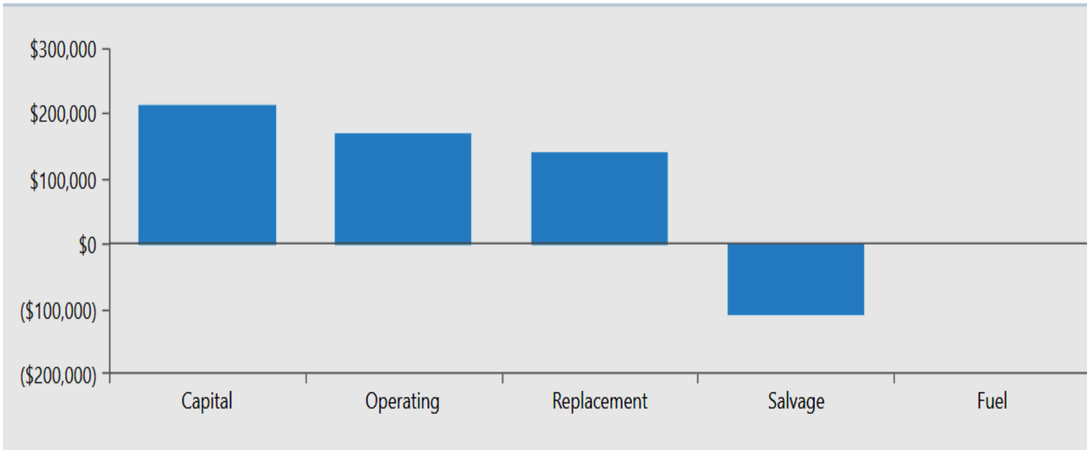

Fig. 7. Cost distribution of Solar-Grid (SG) system over 25 years

Solar-Grid (SG) system: On simulating another (SG) system (Test B configuration), also over a period of 25 years, the system recorded a total NPC of $422,558.31, with majority of the costs being associated to capital and operating costs, as shown in Fig. 7. While this is significantly lower than the NPC of the base system, it also poses a challenge of high initial setup cost and partial reliance on unstable grid electricity without provision for a backup in a case of unmet electricity demand. Table 5 covers the economic analysis of the Solar-Grid system.

This configuration (Test B) has an LCOE of $0.1436 and a yearly operating cost of $5102.62, which are also lower than those of the base configuration. However, with an initial capital of $216,922, ROI 12.5% of and a discounted payback period of 5.28 years, this may not be the most economical option for the healthcare facility.

Solar-Grid-Gen. (SGG) system: On simulating the Solar-Grid-Gen. (SGG) system (Test A) configuration over a period of 25 years, results, as shown in Fig. 8 were obtained. Table 6 also presents the details of the economic analysis of the system.

The total NPC for the SGG system is $382,263.33 with the majority of the costs incurred from capital, operating and maintenance costs, as shown in Fig. 8. The system also generates $59,531.79 in salvage costs. The SGG system can be said to be almost independent of grid electricity with, a total purchase of 113 kWh/yr at a cost of $856.77. This is due to the system generating enough electricity to meet the maximum load demand of the facility, which is 64,273 kWh/yr. The Solar PV system generates 88,046 kWh/yr. This brings about an excess electricity of 12,112 kWh/yr. So far, it is the most economical option out of the three configurations considered.

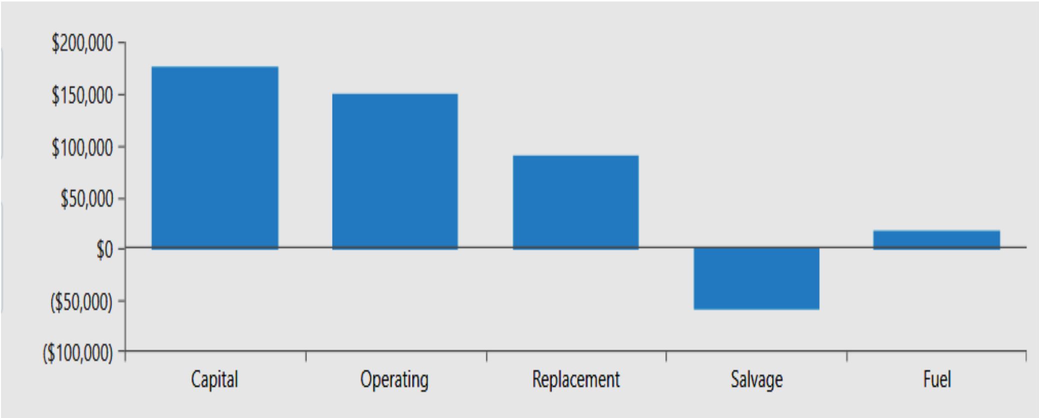

Fig. 8. Cost distribution of Solar-Grid-Generator (SGG) system over 25 years

Having discussed the results of various simulation scenarios, a summary of the cost analyses of both GG (base/highest-cost) and SGG (lowest-cost) systems are as shown in Table 7.

As shown in Table 7, while the GG system in use by the healthcare facility incurred an NPC of $1,663,158.11, the SGG system generated a total NPC of $382,263 over the simulation lifetime (25 years), realising a total savings of $1,280,895.11. The system payback period is 4.8 years, with an ROI of 16% and an IRR of 20%. Table 8 shows a summary of the economic metrics of the lowest-cost (SGG) system.

The levelized cost of energy for the optimal system is $0.1390 while the operating cost of the system is $5,083/yr as against the base system where the levelized cost of energy is $0.642 with an operating cost of 41,269/yr. This shows that the integration of solar PV is a much more economically viable option for the healthcare facility on the long run. Fig. 9 shows the graph of the cost savings of the SGG system against the base system over time.

The lowest cost (SGG) system starts out as more expensive due to the high initial setup capital required, but due to the low operating and maintenance costs, it is able to save a lot of cost overtime that would have otherwise been incurred for fueling in the base system.

It is very important to note that while this might be the most cost-effective of all options, Initial investment cost is a major barrier to the implementation of this system, as the facility under observation is a medium-scale privately owned healthcare facility. Another possible challenge in the implementation of the lowest-cost system is that of space constraint (for panels and batteries installation).

Table 7. Cost Comparison of the base and lowest-cost systems

Summary	GG (Base) System	SGG (Lowest-Cost) System
Total NPC	$1,663,158.11	$382,263
Initial Capital	0.00	$177,437
Operating Cost	$41,269/yr.	$5,083/yr.
Levelised COE	0.642/kWh	0.139/kWh

Table 8. Economic metrics

Metric	Value
Present Worth ($)	1,280,895
Annual Worth($)	31,784
Return on Investment (%)	16.2
Internal rate of return (%)	20.3
Simple Payback yr.	4.83
Discounted payback yr.	4.39

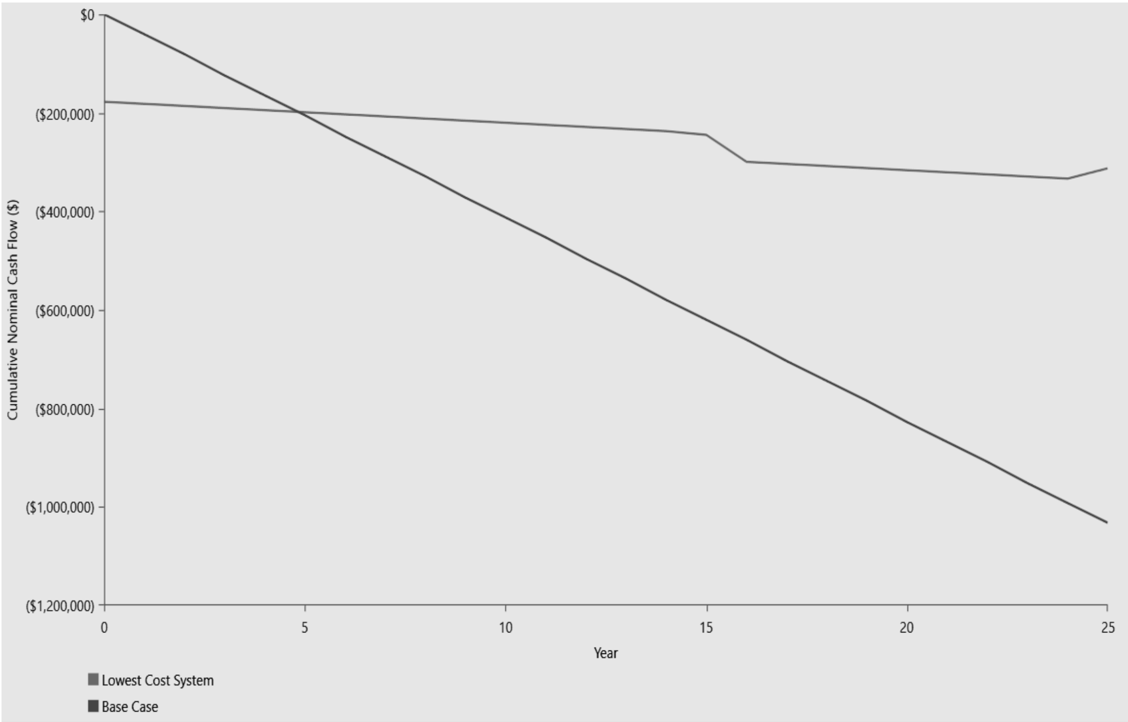

Fig. 9. Graph of cumulative nominal cash flow against time

3.5 Qualitative Benefits of the SGG System: Practical Implications

Some of the benefits of the SGG configuration cannot be quantified by cost as monetary value cannot be attached to them. Some of these benefits are listed below;

1. **Increased Energy Security and Resilience:** By introducing a renewable energy source like solar PV, the system becomes less dependent on the main grid. This reduces the risk of outages caused by grid failures or disruptions. Even during partial outrages, the PV system can provide a sufficient level of power, keeping critical equipment operational.
2. **Reduced Dependence on Fossil Fuels:** A solar PV system generates clean energy, decreasing the reliance on fossil fuel-based power plants. This translates to lower greenhouse gas emissions and a smaller environmental footprint for the entire healthcare system which is important, as Nigeria is one of the largest greenhouse gas producers in West Africa.
3. **Improved Quality of Healthcare:** A stable and reliable electricity supply is crucial for maintaining critical medical equipment and ensuring uninterrupted patient care. Even though the base system also ensures 24-hour electricity supply, the frequent interruptions, and changeovers were a major problem to equipment for life support, diagnostic tools, and temperature-controlled storage for medications and vaccines. Consistent power also improves the overall environment for both patients and staff, enhancing the quality of care provided.
4. **Potential for Lower Energy Costs:** HOMER simulations have considered the cost of both grid electricity and the PV system over the simulation lifetime of 25 years. The analysis showed stable electricity with the hybrid configuration, this suggests a significant potential for long-term cost savings. The PV system also offsets a large portion of the electricity needs, greatly reducing reliance on potentially expensive grid power.
5. **Potential for Increased Property Value:** An integrated renewable energy system can make a property appear more appealing and eco-friendly. This might result in higher property values, particularly for structures like hospitals where energy efficiency is becoming more and more crucial.

4. CONCLUSION

In this study, the economic analysis of integrating a solar photovoltaic (PV) system into the existing energy infrastructure in a healthcare facility in Nigeria has been appraised. Findings showed the optimal system configuration to be the Solar-Grid-Generator (SGG) system, comprising of solar PV panels, lead-acid batteries, a system converter, alongside existing national grid and diesel generator. This hybrid system has a significantly lower net present cost (NPC) of $382,263, compared to the base case scenario of $1,663,158, which relies totally on grid electricity and the diesel generator. The levelized cost of energy (LCOE) for the hybrid system is $0.139/kWh, which is also much lower than the base case LCOE of $0.642/kWh.

Also, integrating solar PV systems with existing energy infrastructure in a healthcare facility, considering the facility's load profile and energy demand patterns, solar resource potential, and the requirement for power backup from diesel generator was successfully modeled and simulated.

Beyond economic benefits, the Solar-Grid-Generator (SGG) system also offers qualitative benefits that cannot be quantified by cost. It increases energy security and resilience by eliminating reliance on the main grid and diesel generators. The integration of a solar PV system which is a renewable energy source also contributes to a lower environmental footprint and reduced greenhouse gas emissions. The stable and reliable electricity supply facilitated by this system can improve the quality of healthcare services provided at the facility.

Finally, this study successfully demonstrated that integrating a solar PV system with the existing energy infrastructure at the healthcare facility in is not only economically feasible, but additionally offers significant long-term cost savings, as well as contributing to environmental sustainability and improved healthcare services. However, the implementation of such a system may face challenges of initial high investment costs and space availability for the installation of solar panels and batteries. Implementing solar integration projects can only be easy with access to financial support mechanisms and or, intervention from government. By offering tax breaks, grants, or facilitating access to low-interest loans specifically for solar projects, governments can significantly improve the financial attractiveness of solar power for healthcare facilities. These incentives will not only encourage wider adoption, but will also contribute to achieving the national renewable energy goals.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, *etc.*) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Information on Energy Consumption of The Selected Healthcare Facility in Ikeja, Lagos, Nigeria

S/N	Hospital Equipment	Peak Power Usage	Minimum Power Usage	Duration of Usage (hrs)
1	Lightnings	3.24	1.24	24
2	Fans	3.46	1.33	24
3	A.C	5.68	2.77	24
4	T.V	5.26	1.79	20
5	Phone and Laptop Charging	3.4	1.08	18
6	X-Ray	5.75	7.21	7
7	CT Scanner	8.23	6.04	7
8	Ultrasound Machine	3.95	2.16	10
9	Patient Monitor	0.55	0.25	24
10		5.34	3.11	6
11	Defibrilator	0.58	0.21	15
12	Dialysis Machine	3.28	2.41	6
13		0	0	0
14		0	0	0
15		0	0	0
	Submeter Data (Electricity):	**Department Monthly Consumption (kWh)**		
	Department Monthly Consumption (kWh)			
	Emergency Room	3,400		
	Operating Rooms	5,440		
	Inpatient Wards	8,160		
	Laboratories	2,720		
	Cafeteria	1,700		
	Adminstration	1,020		
	Month	**Electricity (kWh)**		

January	5,440
February	5,100
March	4,900
April	4,760
May	4,900
June	5,780
July	6,120
August	5,980
September	5,580
October	5,300
November	5,165
December	5,580

Weekends	**Load Profile**			
Time	**0_6**	**6_12**	**12_18**	**18_24**
JAN	14.33	16.78	26.78	36.11
FEB	10.22	12.98	19.75	35.09
MAR	12.56	16.34	18.67	37.22
APR	11.33	25.57	20.22	33.99
MAY	15.34	17.32	38.21	33.99
JUN	16.43	12.27	34.56	35
JUL	17.57	12.45	34.97	36.63
AUG	12.34	13.54	35.66	36.05
SEPT	13.34	10.45	23.76	35.34
NOV	28.45	13.43	21.88	36.12
DEC	15.67	11.44	22.87	37.43

Weather Data:

Month	**Average Temperature (oC)**	**Average Humidity (%)**
January	25.9	65
February	26.94	60

Weekends	**Load Profile**			
March	27.22	55		
April	26.99	50		
May	26.35	45		
June	25.5	40		
July	24.65	45		
August	24.41	50		
September	24.92	55		
October	25.55	60		
November	26.2	70		
December	26.01	70		
Fixture Type	**Number of Fixture**	**Wattage**	**Operating Schedule**	
Fluorescent	120	28W	6 AM - 8 PM daily	
LED	60	15W	24/7	
Building Size (Sq. ft.)	**Number of Floors**	**Building Age (Years)**	**Construction Materials**	**Window Types**
26,800	**2**	**21**	**Concrete, Steel, Brick**	**Double-paned**

Weekdays	**Load Profile**						
Time	**0_3**	**3_6**	**6_9**	**9_12**	**12_1 5**	**15_18**	**18_21**
Jan	6.043	7.34	19.44	36.34	24.25	26.03	29.33
Feb	4.643	7.13	19.75	36.11	24.87	25.43	35.34
Mar	5.46	6.88	18.67	35.09	24.65	24.67	38.21
Apr	6.222	6.78	20.22	37.22	21.28	25.54	34.56
May	7.03	7.11	20.33	33.99	23.76	24.44	34.97
Jun	6.98	7.28	19.75	35	22.97	27.87	35.66
Jul	5.77	6.88	19.55	36.63	24.64	25.77	35.56
Aug	6.043	6.86	19.47	36.05	24.25	25.23	35.33
Sept	4.65	7	20.66	35.34	23.76	25.99	34.65
Nov	5.87	7.24	19.75	36.12	21.88	24.86	33.45
Dec	6.44	6.98	19.85	37.43	22.87	23.98	35.34

Weekdays	**Load Profile**		
	Occupant Type	**Number**	**Occupancy Schedule**
	Patients	30	24/7
	Staff (Doctors/Nurses)	35	7 AM - 7 PM (Weekdays)
	Staff (Admistrative)	15	8 AM - 5 PM (Weekdays)
	Visitors(Avrg)	30 10AM-8PM(DLy.)	

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