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Research article

Evaluation of a hybrid solar power system as a potential replacement for urban residential and medical economic activity areas in southern Nigeria

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Abstract: A hybrid solar power system (HSPS) is an alternate method of supplying electricity that can reduce fuel usage while maintaining power supply security. In this study, the efficiency of HSPS, which consists of Grid Supply (GS), Diesel Power Generation (DPG), Solar-Photovoltaic (SPV), and Battery Storage (BS) systems, was evaluated in two economic activity areas (EAAs) in Southern Nigeria. The cross-sectional research design was used, and the research was based on Behera's energy-led growth theory. Urban-residential and Health were the EAAs considered and chosen using a stratified random sample technique. Southern Nigerian states of Oyo and Lagos provided the samples, which were combined and used for the study. Electricity consumption was calculated using electricity load demand for the two EAAs from 2008 to 2017. For each EAA, an Integrated Renewable Energy

Mini/Microgrid Model (IREMMM) based on power load demand and solar irradiation was constructed. Levelized Cost of Electricity (LCOE) (/kWh), and Net Present Cost (NPC) (M) were calculated for one hybrid configuration, SPV-DPG-BS-GS, and two standalone configurations, DPG and SPV-BS. Configurations with SPV integrated had lower LCOEs than DPGs in both EAAs. In Southern Nigeria, solar PV combinations with battery storage provided the highest performance for a hybrid power system. In the medical contexts, a hybrid power system achieves higher overall performance.

Keywords: hybrid power system; solar photovoltaic; levelized cost of electricity; net present cost; economic activity area

1. Introduction

Renewable sources of energy are considered cleaner and less polluting than traditional fossil fuel-based power sources and are growing widely in the renewable energy market and also continued to expand even, during economic recessions [1–3]. The establishment of a renewable energy project offers an energy-efficient low-cost power plant for future generations that produces electricity with little or no environmental impact [4–6]. The development of a large asset portfolio generation decreases a nation's dependency on any one technology or fuel, as well as its sensitivity to supply volatility and higher prices [7,8]. The major long-term advantage of sustainable technology solutions is the full ownership, and installation of a renewable plant, and a renewable, environmentally responsible, and cost-effective energy system for the country [9,10]. Examining some of the major Distribution Companies (DISCOs) in Nigeria, such as Ibadan, Ikeja, and Benin, it is clear that feasible integration of distributed generation (both non-renewable and clean energy sources) is critical for decreasing power loss; satisfying end-user demands, by assuring essential load energy supply, and integrating the community in power supply. However, a suitable mix of energy supplies to address the various inadequacies in electricity in Nigeria is yet to be determined. It is now impossible to replace traditional diesel generators since renewable energy sources are unstable [11,12]. To maximize the benefits of each system, HES that blends traditional and renewable power sources may be an efficient solution [12]. However, several aspects, including technological, financial, and environmental issues, must be considered to build a hybrid renewable energy system that yields the required results.

Many studies have been conducted on hybrid energy systems that blend conventional and renewable power sources to obtain an optimum combination. Using HOMER energy optimization software, Adaramola [13] investigated the viability of a solar PV-grid connected energy system for power generation in a chosen area in the northern portion of Nigeria. Investigations were made into the economic and technical performance of an 80-kW solar PV system linked to the grid. It was discovered that the energy system can create annual electricity of 331,536 kWh, with solar PV contributing 40.4% and the LCOE of \$0.103/kWh, at base case solar PV cost of \$2400/kW and globally averaged solar radiation of 6.0 kWh/m^2/day. The installation of grid-connected solar PV systems in the northeastern region of Nigeria may be economically feasible based on the study's findings. Shahnia *et al.* [14] concentrated on the design of a suitable standalone energy supply system for a remote island in Western Australia. Several layouts were investigated to lower the COE generation and to establish the most economically feasible solution for the island. The options under consideration range from a whole diesel generator-based alternative to a hybrid system that includes a solar farm, battery energy storage, wind turbines, and diesel generators. Each system was examined using HOMER software and using the real demand statistics of the island, as well as the pricing of various electrical parts in the Australian market. The system with the lowest NPC and the lowest LCOE during the project's lifespan was selected and recommended as the most cost-effective option. Using LCOE and NPC of the system, Adaramola *et al*. [15] conducted an economic analysis of the viability of using a HES consisting of diesel generators, wind, and solar for use in rural areas of southern Ghana. At the chosen site, the annual mean wind speed was 5.11 m/s, and the annual mean daily sun global radiation was 5.4 kWh/m^2/day. Their study was conducted using HOMER software. The simulation model incorporated both actual load data and wind data. A mix of 791.1 MWh of power was discovered to be produced annually by two generators with a combined capacity of 100 kW, an 80 kW PV array, a 60 kW Surrette 4KS25P battery, a 100-kW wind turbine, and a 60-kW inverter/converter. It was determined that the power price for this hybrid system was $0.281/kWh. Buragohain *et al*. [16] evaluated the technical, economic and environmental evaluation of a hybrid 3.5 kVA biogas-fueled generator and 1 kW solar photovoltaic plant (with battery backup). Energy sharing between the combined systems was examined when the hybrid system was operated under constant load settings ranging from 20% to 80% of the rated power conditioning unit. The hybrid system had an LCOE value of $0.21/kWh, and a high positive net present value of $1562.15 according to economic research during a project lifetime of 25 years. The analysis of the system advisor model yielded a positive net present value of $306.45 and an LCOE value of $0.15/kWh. To meet the intended electric load of a residential community situated in a desert area. Ghenai *et al*. [17] optimized the design and developed dispatch control techniques of the standalone hybrid renewable power system. In a desert environment, the design and functionality of the hybrid power system were examined for the impacts of temperature and dust buildup on solar PV panels. The planned off-grid hybrid renewable power system was environmentally beneficial, with an LCOE of $145 MWh and a 40.2% renewable portion. Rehman and Al-Hadhrami [18] investigated a hybrid power system for a distant population near Rafha, Saudi Arabia, using solar PV, diesel, and batteries. An ideal power system for the hamlet was determined using the hourly solar radiation data recorded at the site, four generators of varying rated powers, PV modules mounted on fixed foundations, varied sizes of batteries, diesel prices ranging from 0.2 to 1.2 US$/l, and converters. For a 0.2$/l diesel price, the COE of a diesel/PV/battery power system and a diesel-only power system with 21% solar penetration was found to be 0.219$/kWh and 0.190$/kWh, respectively. The sensitivity analysis revealed that at a 0.6$/l diesel price, the COE from the hybrid system approaches that of the diesel-only system and that above that price, the hybrid system becomes more economical than the diesel-only system. Gebrehiwot *et al*. [19] investigated the feasibility of a hybrid system for electrifying a remote rural Ethiopian community. The HOMER model was used to evaluate primary data, create a load profile, and determine the best least-cost system alternative for the hamlet. To investigate the influence of differences in wind speed, solar radiation, and fuel price on ideal system configurations, a sensitivity evaluation was conducted. The results revealed that a hybrid system comprising a battery, solar array, diesel generator, and wind turbine was the most cost-effective choice. The cost of energy generation to meet the village's daily peak demand of 19.6 kW was projected to be $0.207/kWh, with a net current cost of 82,734 dollars. When compared to diesel-only energy generation, the best system provided a reduction of 37.3 tonnes of CO_2 emissions per year. Several other studies on hybrid solar power system was reviewed by Ismaila *et al.,* [20].

However, although many researchers focused on the technical and financial performance of the hybrid solar power system in urban-residential, industrial, and agricultural economic activity areas (EAAs) to increase access to energy, with less attention paid to quaternary EAAs like hospitals. To address this gap, in this study, a hybrid off-grid energy system model that is efficient and serves two unique economic sectors-urban residential and, most significantly, medical institutions are outlined. To increase access to electricity in these chosen areas of Nigeria, technological and economic analyses based on grid supply, diesel power generation, and solar-photovoltaic systems were conducted.

2. Material and methods

This section outlines an efficient hybrid off-grid renewable energy system concept that caters to two different sectors of the economy, such as residential and health care. In order to increase access to electricity in these chosen areas of Nigeria, technological and economic analyses based on grid supply, diesel power generation, and solar-photovoltaic systems were conducted. The area of economic activity under evaluation is located in the states of Lagos and Oyo. Lagos and Oyo states were both chosen for the research effort because to their populations, popularity, and wide physical land area. The chosen research sites are intended to represent the commercial heart of Southern Nigeria. They were chosen for this operation because, in comparison to other Southern Nigerian states, these locations have a lot of economic activity going on. Lagos is the most metropolitan region in Nigeria and on the continent of Africa. Lagos is Nigeria's economic capital and a sizable investment hub for all of Africa. The fourth-highest GDP in Africa is located in this city. It is among the cities with the quickest population growth. On the other hand, Oyo state covers an area of close to 28,454 square kilometres and rises progressively from 500 metres above sea level in the south to roughly 1,200 metres. The hypothetical economic region areas are shown in Table 1.

Table 1. Hypothetical economic region areas considered.

S/N	Economic activity area	Sector	State	Longitude	Latitude
1	Commercial housing complex	Residential	Lagos	6.3212°N	3.2344°E
2	Muslim medical centre	Health	Oyo	6.2419°S	106.8616°E

2.1. Detailed information of the research areas

2.1.1. Muslim Medical Centre (MMC), Saki, Oyo State

The MMC is an Oyo state missionary clinic in Saki West LGA, Saki, Oke. The medical center serves a wide range of people and includes healthcare facilities such as a midwifery college, nursing school, and a medical laboratory school. Outpatient facilities (imaging or radiological treatments), diagnostic facilities, physical therapy, and medical rehabilitation services are also run by the MMC. Other facilities offer gynecology and obstetrics services, as well as surgery (cardiovascular and pediatric surgery), emergency care, and primary medical care. The medical center has approximately 5 departments, each of which requires power to provide the basic needs of operating equipment, heating, cooling, pumps, and vital utilities for the student dormitories and doctor's apartments. The general power supply to the clinic has been gruesome, averaging around less than 2 hours a day, and the use of diesel-powered generators has been used, which has proven very costly. The hospital presently uses 3 generator sets of 5–35 kilo-Watts power ratings, which are alternatively used to meet regular hospital services and specifications for nighttime. The study looked at the probable and economic benefits of incorporating a green energy source into the clinic's energy supply mix.

2.1.2. Commercial Housing Centre (CHC), Ibeju-Lekki, Lagos State

The investigation's second focus is on a modern lodging and industrial building at Lagos, which should include the following features: A sawmill, a laundry room, a flour mill, and a cinema are among the 600 house dwellings, as well as a retail centre with twenty general purpose stores, a flour mill, and a sawmill. The retail and residential complex will be powered by the current distribution system and will also have access to a diesel-powered generator. The report explores the viability and economic advantages of the renewable energy program's incorporation into the complex.

2.2. System components

The temperature profile, solar irradiation, and wind speed of the research locations were generated via the NASA website. The hybrid optimization model for electric renewable energy simulates the facility's operational circumstances by preserving energy equilibrium measures for each phase of the year. A converter, PV, battery, solar, and diesel generators are all components of the proposed HRES. The generator taken into consideration for the research study has the general specifications as listed in the HOMER programme. The designed generator has a capital and replacement cost of 132.02/kW, an operating lifetime of 15000 hours, and an operating cost and maintenance of 13.20/h. This model's fuel costs 250 yen per litre. Each battery costs $75,537; replacement costs are set at $75,537; and operation and maintenance costs are set at $75,537 and $0/yr., respectively. The project will last for ten years, and it is predicted that the yearly real interest rate will be 2%. In this assessment, the shortage capacity factor is considered to be zero, implying that no demand is unmet. This will boost system efficiency because this is a vital component in the sectors chosen. HOMER rates the best system based on the NPC generated for each particular module. The NPC is the amount deducted from the investment, replacement, and repair costs during the system's working life. An energy audit was performed on the place to determine the energy needs or use of an EAA. The energy audit estimates the amount of energy utilized by the EAA as well as the amount of energy required to power all of the electrical equipment in the EAA. Using HOMER, the carbon emissions of the grid and the generator were calculated. Because the boiler and the generators both use fuel with known properties, HOMER models their emissions similarly. The grid model has been somewhat modified. Before modelling the power system, HOMER determines the emissions factor for each pollutant (kilogramme of pollutant emitted per unit of fuel consumed). After the simulation, the annual emissions of that pollutant are computed by dividing the emissions factor by the total fuel use for the year. When simulating a grid-connected system, HOMER determines the net grid purchases, which are calculated as total grid purchases minus total grid sales.

2.3. Optimization of the system

The goal of energy system optimization is to make the system as efficient and perfect as possible. HOMER investigates an energy system that effectively provides the demand for electrical energy with a total required NPC, subject to other established technical constraints. The sensitivity of input parameters can also be determined. The energy that the system can offer at each stage level is compared to the thermal and electric demand throughout the time phase. When fuel- and battery-powered generators are connected to the grid, HOMER analyses the activity in each phase of the period. If the batteries need to be charged or discharged, cycle charges and load-following are used. The cost of the system's lifespan (discounted sum of the initial investment, replacement, maintenance and operation, interest charges, and fuel) is calculated up to the demand is met by the combination of the modules. Additionally, sensitivity analysis on non-linear input can be applied. As mentioned earlier, HOMER software was used in analyzing the two EAAs. To evaluate the effectiveness of HES, many assessment metrics that are acceptable for the intended goal may be utilized. Environmental (renewable energy fraction, and emission reduction) or technical (LCOE, simple payback period, NPC).

2.4. Integrated Renewable Energy Mini/Microgrid Model (IREMMM)

IREMMM is a composite electric power system that receives electricity from three primary power plants such as distribution firms' grid supply, self-generation from diesel generators and gas, and single photovoltaic systems with a battery bank in various combinations to meet existing energy needs and usage in the two distinct economic activity areas. The combination is determined by availability, technological restrictions, and costs. Table 2 shows the expected combined electrical power system combination. In two areas of substantial economic activity, the IREMMM produced in this work will be employed as an empirical model: A medical center, and a residential building.

Table 2. Combination of IREMMM power source.

Combinations	Power-supply-sources		
	Supply from grid	Self-Generation	Solar PV
I	0.6	0.0	0.4
II	0.6	0.4	0.0
III	0.6	0.2	0.2
IV	0.4	0.3	0.3
V	0.4	0.1	0.5
VI	0.4	0.5	0.1
VII	0.2	0.4	0.4

3. Results and discussion

The HOMER Pro simulation results for two different study regions are provided. Each research area has a stand-alone diesel generator, a hybrid PV-grid-connected system, and a stand-alone solar PV system. Because each study area had different electricity demands and energy system sizes, any comparison in that area could only be made between the Standalone Diesel Power Generator System (DPG), Standalone Solar PV System (SPV-BS), and Hybrid Solar PV-Diesel Power Generator-Battery Storage-Grid System (SPV-DPG-BS-GS).

3.1. Commercial Housing Complex, (CHC)

3.1.1. Standalone diesel generator

A diesel generator that was connected to a busbar that carried power to the load made up the freestanding diesel system. Figure 1 shows the configuration of commercial housing complex standalone diesel generator. The daily energy use was 227.60 kWh, with a peak demand of 42.4 kW. Cycle charging was the employed dispatch strategy. Due to the generator's ability to scale itself, the total amount of power produced and used during the year was 83,074 kWh/yr. The mean electrical output measures the generator's average electrical power production over the hours it runs; in this case, it was 9.48 kW, 0.434 kW and 42.2 kW, respectively, were the minimum and maximum electrical outputs that represented the lowest and highest electrical power outputs of the year. The generator produced 95,773 kg/yr. of CO_2 emissions. The system produced no excess electricity since the generator was automatically sized to suit the demand, hence there was no unmet load and no excess electricity. The system utilized 35,283 L of fuel per year, with a specific fuel consumption of 0.425 kWh. The NPC of the diesel generator was calculated to be $323,490 with an LCOE of $0.42/kWh for the full lifetime of the system using HOMER. The LCOE was estimated using economic input and a diesel price of $0.639/L. The entire annualized system expenses for the generator were $35276.66, however the biggest expenditures were incurred due to resource costs, which included the cost of purchasing diesel. Table 3 shows the annualized costs for the CHC diesel generator.

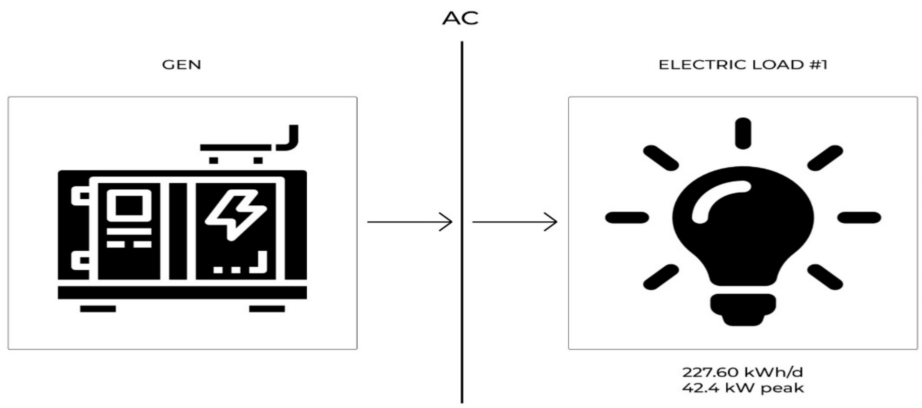

Figure 1. The architecture of commercial housing complex standalone diesel generator.

Table 3. CHC diesel generator annualised cost.

Name	Capital	Operating	Replacement	Salvage	Resource	Total
CHC Gen. ($)	1.58	12711	7.30	–0.22	22557	35276.66

3.1.2. Hybrid system

The system architecture shows that the peak load was 42.24 kW, and the daily energy demand was 227.6 kWh/d (see Figure 2). Two busbars that were connected to the grid, the diesel generator, and the PV array made up the hybrid system. The system also sold any extra energy it produced to the grid. The converter, which served as both an inverter and a rectifier, was linked to the busbar. The diesel generator was intended to serve as a backup power source in the event that solar power was not available or there was a grid power loss. The busbar was linked to the load in order to supply electricity to the load. The system reported an overall NPC of -$15896.7 and an LCOE of $-0.0051/kWh. Due to high initial capital expenses, the Solar PV system had the highest costs, coming in at $3350.385. Despite the fact that the capital expenses for the grid were always nil, the system converter had annual costs of $1485.555, making the overall system cost of $-1762.53. The grid's operations and maintenance expenditures came to the lowest overall cost of $-6598.47, although they were equal to the yearly cost of purchasing power from the system, less any revenue from sales to the grid. The negative number made it clear that more grid sales were generated with the extra energy the hybrid system produced. Table 4 shows the annualized costs for the CHC hybrid system.

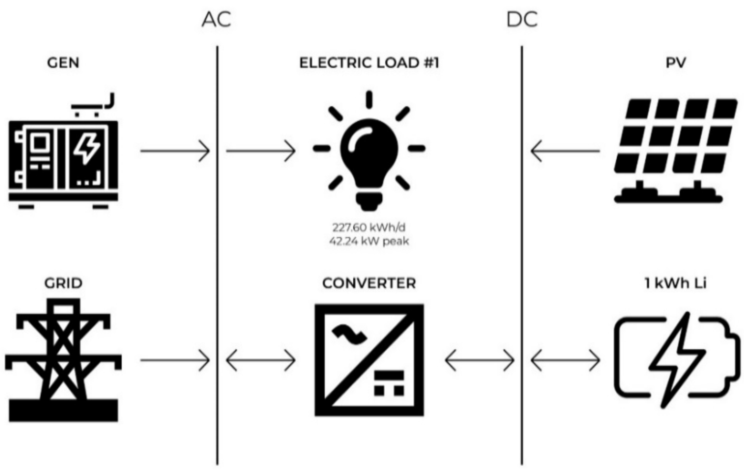

Figure 2. The architecture of commercial housing complex hybrid system.

Table 4. CHC hybrid annualised costs.

Name	Capital ($)	Operating ($)	Replacement ($)	Salvage ($)	Resource ($)	Total ($)
PV	6879.795	0.00	0.00	–3529.41	0.00	3350.385
Grid	0.00	–6598.47	0.00	0.00	0.00	–6598.47
Converter	2075.051	0.00	0.00	–589.496	0.00	1485.555
System	8954.846	–6598.47	0.00	–4118.91	0.00	–1762.53

The total amount of electricity produced in a year was 359,114 kWh, of which 318,738 kWh came from solar panels and 40,376 kWh originated from grid purchases. Grid penetration was 11.2%, and the penetration of renewable energy was 88.8%. There was no unmet electrical load, but there was 5402 kWh of extra electricity produced annually. The grid supplied electricity when there was not enough power from renewable sources to fulfil demand, and it also drained energy from the battery when there was no grid to assure supply continuity. In the event that solar energy proved insufficient to fulfil the demand, solar was employed as the primary alternative to supply energy to the load. This was supported by the grid. When solar power was not available or there was a grid power outage, the diesel generator was designed to function as a backup power source. This is why the hybrid system's results showed no evidence of energy coming from the generator. Table 5 displays the annual energy produced, energy provided, and peak demand grid rates for the CHC hybrid system. 40,375 kWh in total were purchased, while 254,971 kWh were sold.

Table 5. CHC hybrid grid rates.

Month	Energy purchased (kWh)	Energy sold (kWh)	Peak demand (kW)
January	3324	25243	30.3
February	2895	23410	28.2
March	3332	25074	32.2
April	3326	23048	30.4
May	3338	21052	32.9
June	3332	16669	33.2
July	3322	16725	27.2
August	3459	16868	31.7
September	3458	17536	32.8
October	3500	21167	31.1
November	3580	22770	42.2
December	3510	25383	35.2
Annual	40375	254971	42.2

3.1.3. Standalone solar pv system

Figure 3 depicts the system architecture for the CHC Standalone Solar PV System. The peak load was 42.24 kW, and the daily energy usage was 227.6 kWh/d. The hybrid system had two busbars that were linked to the battery and the PV array, and the busbar that was also linked to the load had a converter attached to it for powering the load. The Standalone Solar PV System, which consists of the solar panel, converter, and batteries, provided a total NPC of $42,515 and LCOE of $0.062/kWh, as well as total yearly costs of $4620.687, according to the simulation findings. Battery capital expenditures were the system's largest expense, coming in at $3887.468, because seasonal changes made expensive storage solutions like batteries necessary. Annualized costs for the CHC solar PV system are displayed in Table 6. The total amount of electricity generated over the course of a year was 133 971 kWh, with the extra energy being used to charge the battery at a rate of 51, 172 kWh, 8,377 kW made up the unmet electrical load, which was the amount of power that the PV was unable to supply. Due to seasonal changes, this typically occurred when electricity demand surpassed supply. Because it is renewable energy, no pollutants were released.

Table 6. CHC solar PV system annualised costs.

Name	Capital ($)	Operating ($)	Replacement ($)	Salvage ($)	Resource ($)	Total ($)
Generic 1 kW ion	3887.468	0.00	0.00	–899.2609	0.00	2988.207
Flat plate PV	2890.03	0.00	0.00	–1480.803	0.00	1409.227
System converter	311.8491	0.00	0.00	–88.5934	0.00	223.2557
System	7089.347	0.00	0.00	–2468.66	0.00	4620.687

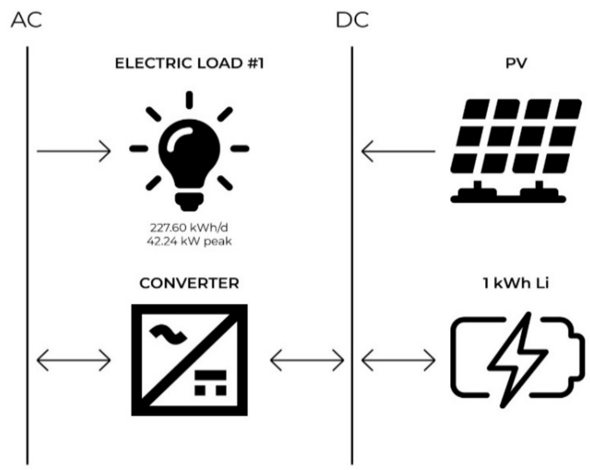

Figure 3. The architecture of commercial housing complex standalone solar PV system.

Figure 4 displays a comparative chart of the three systems for the commercial housing complex. The annualised capital cost for the hybrid system is high compared to the other systems due to the initial purchase of the PV panels and battery storage and as regards the operation, the negative rise in the hybrid system means a sale in grid as a result of extra energy generated by the system as opposed to that of the diesel powered generator which has a positive rise due to high maintenance cost. The resource cost is exceptionally high for the DPG system as result of frequent purchase of diesel fuel to power the system while other systems do not need no resources to make them function.

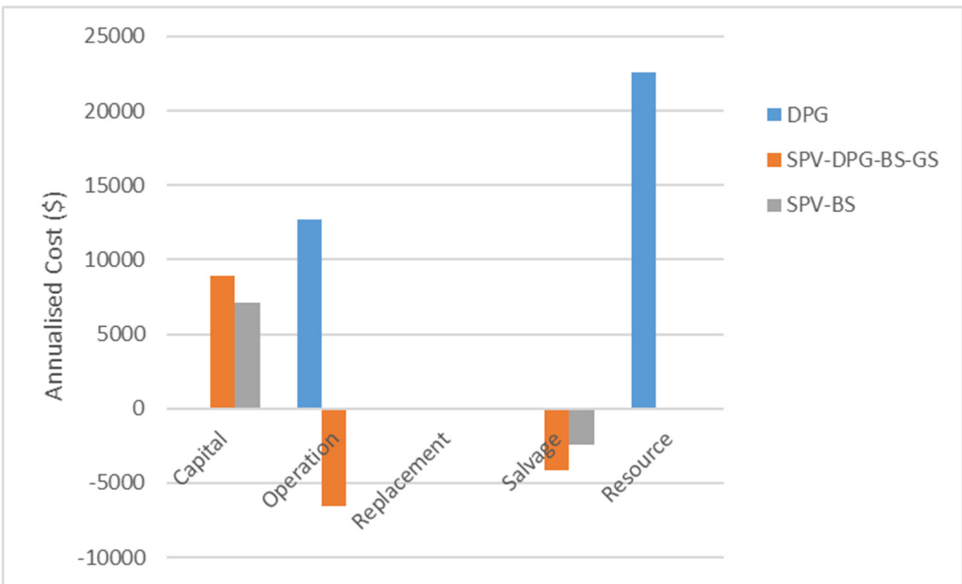

Figure 4. Comparison chart for the three systems of commercial housing complex.

3.2. Muslim Medical Center (MMC)

3.2.1. Standalone diesel generator system

A diesel generator attached to one busbar, which provided energy to the load, constituted up the Standalone Diesel Generator System. The system configuration is shown in Figure 5. The dispatch strategy employed was cycle charging despite the fact that the energy demand was 203 kWh/d, and the peak demand was 29.22 kW. The generator automatically scaled itself, thus the annual total of electricity produced was 74,095 kWh, and the annual total of electricity used was 74,095 kWh. Despite the fact that there was no unmet load and no extra electricity because the generator was automatically sized to meet the load, the diesel generator produced significant pollution emissions, with the stand-alone generator emitting 79,933 kg of CO_2 annually. The system used 29,448 L of fuel annually, using 0.397 kWh of fuel specifically. The average electrical output was 8.46 kW, while the minimum and maximum electrical outputs were 0.106 kW and 29.2 kW, respectively, representing the lowest and highest electrical power outputs of the year. Following the diesel price of \$0.639/L, the standalone diesel system produced a total NPC of \$254012 and an LCOE of \$0.3739/kWh. The entire annualized system expenses were \$27621, and the cost of purchasing fuel accounted for the majority of those expenditures at \$18824. Table 7 displays the annualized costs for diesel generators.

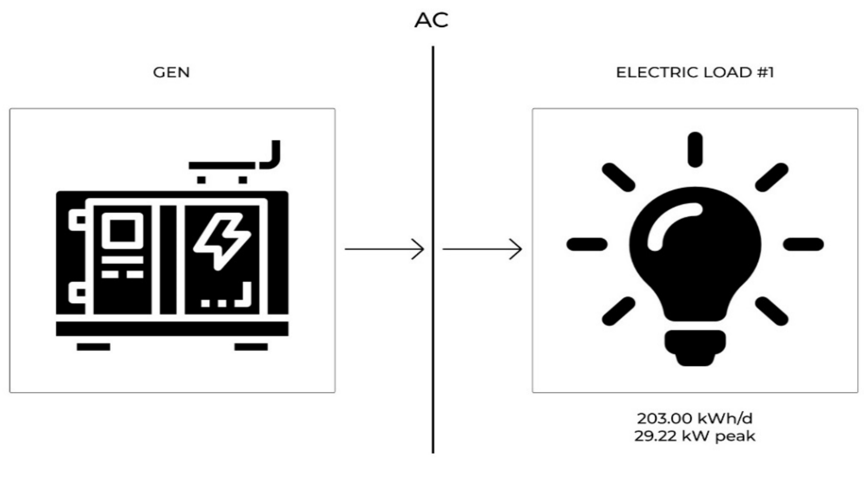

Figure 5. The architecture of mmc standalone diesel generator system.

Table 7. MMC diesel generator annualised cost.

Name	Capital (\$)	Operating (\$)	Replacement (\$)	Salvage (\$)	Resource (\$)	Total (\$)
MC Gen	1.10	8874.68	5.09	–0.15	18823	27703.7

3.2.2. Hybrid system

The peak load was 29.22 kW, and the daily energy demand was 203.00 kWh/d. The diesel generator and the grid were connected to the PV array via two busbars that made up the hybrid system. The configuration of MMC hybrid system is presented in Figure 6. The system also sold any extra energy it produced to the grid. In order to send electricity to the load, a converter that could serve as both an inverter and a rectifier was attached to the busbar. When solar power was not available or there was a grid power outage, the diesel generator was designed to function as a backup power source. Based on the outcomes of the simulation, the system produced a total NPC of $-14294 and an LCOE of $-0.0056/kWh. The solar PV system had the highest expenses of $3018 according to the cost summary for the total system per year, which was caused by high initial capital costs. The system converter cost $1226.4 per year, while the total cost of the grid for operations and maintenance was $5806. The annual cost of purchasing power from the grid, minus any revenue from the grid's sales, was equal to the cost of grid operations and maintenance. Although the total system cost was minus $1546.52, the negative value clearly showed that more grid sales were made from the excess energy generated by the hybrid system. The annualized costs of the Muslim MC Hybrid system are broken down in Table 8.

Table 8. MMC hybrid annualised costs.

Name	Capital ($)	Operating ($)	Replacement ($)	Salvage ($)	Resource ($)	Total ($)
Generic 1 kW ion	21.07	0.00	0.00	–5.99	0.00	15.08
Generic flat plate PV	6164	0.00	0.00	–3146	0.00	3018
Grid	0.00	–5806	0.00	0.00	0.00	–5806
System converter	1713	0.00	0.00	–486.6	0.00	1226.4
System	7898.07	–5806	0.00	–3638.59	0.00	–1546.52

Table 9. MMC grid rates.

Month	Energy purchased (kWh)	Energy sold (kWh)	Peak demand (kW)
January	1,091	20,639	17.9
February	911	19,025	10.3
March	1,108	20,079	15.3
April	1,066	18,473	18.2
May	1,113	16,601	16.5
June	1,248	12,885	18.6
July	1,170	12,937	17.6
August	1,379	13,091	16.8
September	1,364	13,713	21.8
October	1,263	16,933	16.7
November	1,331	18,551	17.6
December	1,260	20,773	14.6
Annual	14,303	203,700	21.8

With 14,303 kWh purchased from the grid and 301,314 kWh generated from PV, a total of 301,314 kWh was produced annually. Since there was no grid and renewable energy was utilized 95.3% of the time and the grid was only used 4.75 percent of the time, the battery was employed to maintain supply continuity. The grid provided backup support in the event that solar PV proved to be insufficient to satisfy the demand as the primary alternative for supplying electricity to the load. No energy supplied by the diesel generator was noted in the hybrid system's results because it was designed to function as a backup power source in cases where solar power was not available or when there was a grid power outage. The system supplied power when renewable energy sources were insufficient to satisfy load demand, and it continues to do so even when there was excess power produced, totaling 9650 kWh per year. However, there was no unmet electrical load, therefore there was no excess electricity created. 14,303 kWh in total were purchased, whilst 203,700 kWh were sold. The grid rates for annual energy production and supply are shown in Table 9.

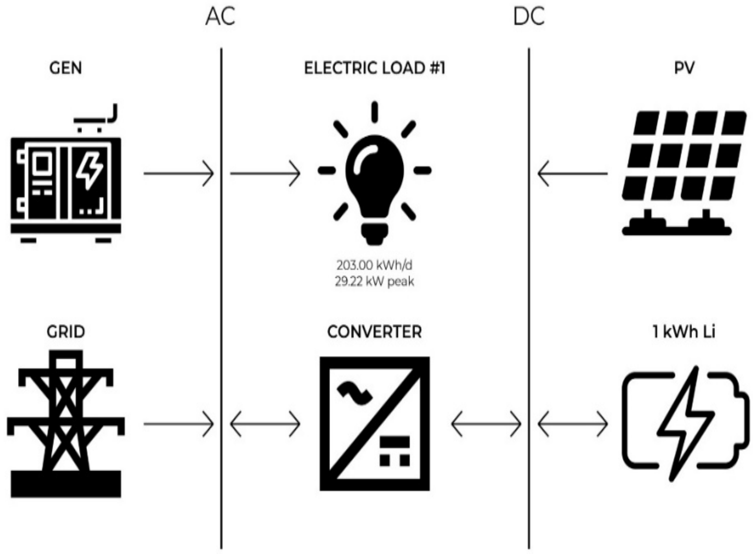

Figure 6. The architecture of mmc hybrid system.

3.2.3. MMC standalone solar PV system

System configuration of standalone solar PV is shown in Figure 7. The peak load was 29.22 kW, and the daily energy usage was 203 kWh/d. Two busbars connected to a converter were part of the hybrid system, which also included a 1 kW Li battery and a PV array. For the purpose of supplying the load with power, the busbar was attached to it. Based on the outcomes of the simulation, the Standalone Solar PV system produced a total NPC of $23397 and an LCOE of $0.038/kWh.

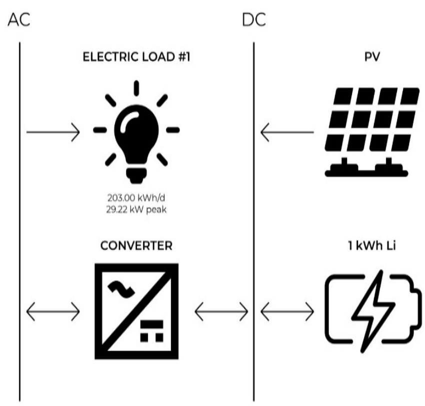

Figure 7. The architecture of MMC standalone solar PV system.

The system's yearly total cost, which considered capital expenditures as well as operating expenses, was $2548.64. The most expensive components of the entire system came from the capital expenses of the storage systems, such as batteries, which were expensive yet necessary due to seasonal changes. Table 10 displays the annualized costs for the Muslim MC PV system. The total quantity of electricity generated in a year was 119,236 kWh, of which 47,580 kWh were surplus. The surplus energy was used to charge the battery. The unmet electrical load, which was 7456 kW, was the load that the PV was unable to meet due to seasonal changes, which typically happened when electrical demand surpassed supply. Because it was renewable energy, no pollutants were released.

Table 10. MMC solar PV system annualised costs.

Name	Capital ($)	Operating ($)	Replacement ($)	Salvage ($)	Resource ($)	Total ($)
Generic 1 kW ion	1432.91	0.00	0.00	–347.87	0.00	1085.04
Flat Plate PV	2557.54	0.00	0.00	–1309.56	0.00	1251.39
System Converter	301.19	0.00	0.00	–85.57	0.00	215.63
System	4291.64	0.00	0.00	–1743	0.00	2548.64

For the muslim medical center, Figure 8 shows comparison within the three systems which is similar to that of the commercial housing complex which shows that implementation of these three system in both urban–residential and health EAAs will offer similar treads and behaviours .

3.3. Environment impacts

Since the diesel generator produced considerable amounts of pollutants, the environmental effects of the pollutants were also determined. HOMER Pro calculated the emissions of six gases: nitrogen oxide, sulphur dioxide, unburned hydrocarbons, carbon monoxide, and carbon dioxide. Most emissions came from carbon dioxide, while the amounts from other gases were essentially non–existent. Table 11 displays a summary of the number of emissions.

Table 11. Quantity of emissions.

Quantity (Kg/yr.)	CHC Gen	MMC Gen
Carbon-dioxide	95773	79933
Carbon-monoxide	582	486
Unburned Hydrocarbon	25.4	21.2
Particulate Matter	3.53	2.94
Sulphur-dioxide	243	196
Nitrogen-oxides	547	456

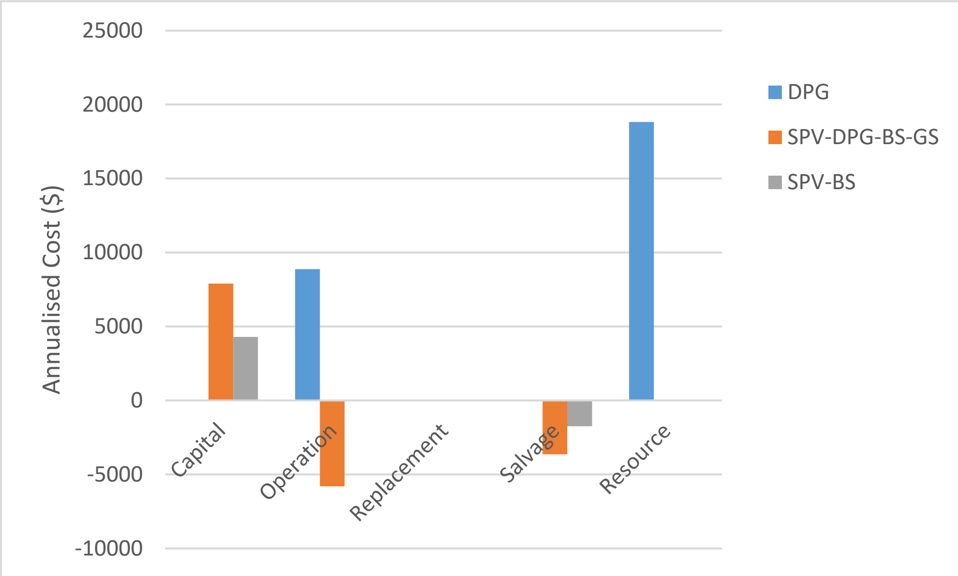

Figure 8. Comparison chart for the three systems of muslim medical center.

3.4. *Further discussion*

The total operating hours for each study region in a year was 8760 h. Simulation yielded the major operating parameters such as annual electrical energy production, annual electrical loads, excess power, renewable energy portion, capacity shortage, unmet loads, and others. The diesel generators utilised in this project were automatically sized to suit the demands, thus there was no excess energy or unmet loads. Homer pro analysed the project's overall economics, which included capital costs, operational costs, replacement costs, salvage costs, resource costs and replacement costs. It was also possible to obtain the net present costs, levelized energy costs, and annualised expenses based on the $0.639/L fuel price. The system with the lowest NPC was the most cost-effective because the net present cost (also known as life-cycle cost) of a component was the present value of all the costs of installing and operating the component over the project lifetime, minus the present value of all the revenues it earned over the project lifetime.

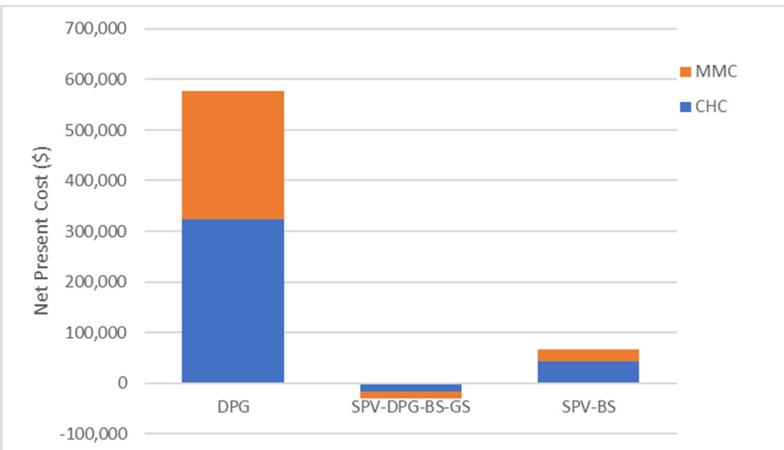

Figure 9. Net present cost offered by the three systems for both EAAs.

The levelized cost of energy, according to HOMER, is the average price per kWh of usable electrical energy generated by the system. The hybrid systems in both study locations had the greatest initial capital costs when compared to standalone diesel generators and standalone solar PV systems, even though a system with the lowest NPC and LCOE was often the best. As shown in Figure 9 and Figure 10, the hybrid systems achieved the lowest NPC and LCOE despite having high capital expenditures. The most energy was likewise generated by the hybrid systems. Therefore, it is safe to state that hybrid systems are more economical than standalone solar PV systems or standalone diesel generators.

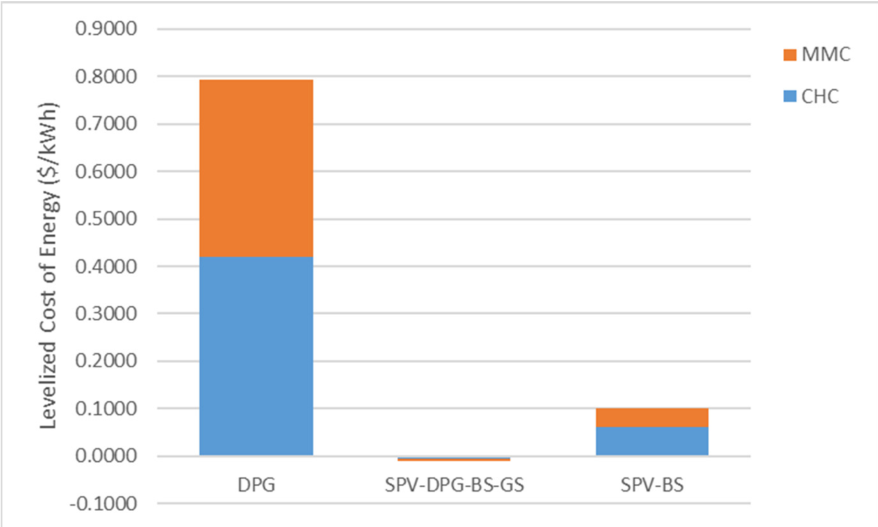

Figure 10. Levelized cost of energy offered by the three systems for both EAAs.

4. Conclusions

Clean energy systems, such as wind turbines, fuel cells, and solar photovoltaic systems are required due to the depletion of fossil fuel reserves and greenhouse gas emissions from fossil fuel consumption. The usage of renewable electricity increased living standards while lowering greenhouse gas emissions. Nigeria's electricity supply is currently unstable from both the grid and standalone solar photovoltaic systems; consequently, several solutions to improve electricity have been suggested, one of which is the integration of alternative energy sources into the nation's overall energy and electricity mix. This evaluation was made to analyse the financial and technical challenges associated with the usage of fossil fuels and promote the integration of renewable energy sources in Nigeria's power sector. Hybrid systems often provide more dependable power. This investigation also attempted to identify and address the challenges associated with combining various energy systems. As Homer Pro has been shown to be a very helpful tool for analysing energy systems, it was employed to carry out the systems evaluation. The primary economic metrics chosen were the levelized cost of energy and net present cost. Two study regions in Nigeria had their energy systems evaluated, and the evaluation's considerations led to the development of three scenarios for power generation that could be contrasted in terms of efficiency and cost. After careful consideration, it was determined that the hybrid combination appeared to be the most cost-effective and reliable alternative for producing electricity. The findings indicated that employing hybrid renewable energy systems over standalone systems has significant benefits over standalone systems, even with high starting expenditures, because hybrid systems have reduced operating and maintenance expenses. In comparison to standalone diesel generators, hybrid systems generated power at the lowest cost and were also viewed as being the most environmentally friendly because they emit less carbon dioxide.

Conflict of interest

The authors declare that there are no known conflicts of interest related to this study that can hinder its publication.

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