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Techno-Economic Feasibility Analysis of an Off-grid Hybrid Energy System for Rural Electrification in Nigeria

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Abstract- Rural electrification improves the quality of life and wellbeing of the rural communities. Diesel generators and woods are the main source of energy for the rural dwellers who are not connected to electricity grid, these sources of energy are not cost effective and are detrimental to the community health due to the release of gaseous pollutants from these sources of energy. Therefore, the use of renewable energy sources as an alternative source of energy for the rural communities become imperative in order to improve socioeconomic activities of these rural communities. In this study, a feasibility analysis on the use of a hybrid solar-wind-battery-diesel system for providing electricity to a rural secondary school is investigated. A village (Moriki) in north western Nigeria is selected for this study with the aim of taking the same study to other parts of the country. A simulation software Hybrid Optimization Model for Electric Renewable (HOMER) is employed to carry out the feasibility study to come up with an optimal configuration in terms of Net Present Cost (NPC) and Cost of Energy (COE). Hybrid solar PV-battery system is the optimal configuration simulated by HOMER with NPC of $18,161 and COE of $0.233/kWh was obtained for a sensitivity case of 6% nominal discount rate. Sensitivity analysis was carried out where wind speed, solar radiation, and nominal discount rate were considered as the sensitive parameters to investigate their impacts on the NPC and COE, the result shows that the sensitivity variables has impact on the NPC and COE. The results also showed a magnificent reduction in greenhouse gas (GHG) emission by 100% because the optimal configuration has 100% renewable fraction.

Keywords Feasibility analysis; rural secondary school; optimal configuration, Hybrid energy system, Nigeria.

1. Introduction

The socio-economic development of every country highly depends on the electricity availability in that country [1]. Nigeria being considered as a developing nation has for many years been trying to improve the standard of living of its people by providing reliable electricity access in both rural and urban parts of the country. The vast population of Nigeria and its target to be among the highest economies in the world requires a significant improvement in its electricity supply to attract investors to set up industries which will subsequently enhance the nation's economy. According to [2] about 80% of Nigeria's rural communities live below the poverty line and this is as a result of lack of development in electricity sector that can enable the rural people to run their small businesses.

Most of the rural communities in developing nations, especially in Africa are not connected to the national grid because of the huge financial implication involved [3, 4], this results to the use of alternative sources such as diesel generators and woods for lightening, cooking, and heating purposes [5, 6]. The use of these fossil fuels causes environmental pollution which of course results in global warming. Since the return of democracy in Nigeria in the year 1999, there has been a tremendous effort on how to extend electricity supply to the rural communities to improve the socioeconomic activities of these rural dwellers [7]. Unfortunately, significant improvement has not been achieved due to political will and corruption in the electric power sectors.

Until this date, the major sources of energy in Nigeria are the hydroelectric source, thermal sources, and fossil fuels. This made it necessary to explore the option of renewable energy sources for clean and reliable energy supply [8-10]. The sources can be exploited in an off-grid mode to provide lasting solutions to the electricity crisis in the rural communities since the connection to the national grid is not feasible due to the huge financial implication involved. For this reason, a lot of researches have been carried out on how to explore these renewable energy sources (RES) for energy generation in both single and hybrid modes depending on the availability of the RES available in the locations [1, 11-14].

Nigeria being blessed with abundant RES especially wind, solar, biomass and hydro [15] has the opportunity of exploring these sources as energy sources in tackling its electricity crisis. It is estimated that Nigeria has an annual average solar radiation of 5.25 KWh/m²/day with an estimated average of 6.25 hours of sunshine hours per day [16, 17]. This shows that solar radiation varies between 3.5 KWh/m²/day to 7.0 KWh/m²/day from the Coastal to the Northern boundaries [18]. The energy that could be generated from the sun was estimated to about 4000 times more than the crude oil produced and 13000 times more than the natural gas produced in Nigeria [12, 15]. Although Nigeria has some drawbacks in wind energy fluctuations in some parts due to the climatic conditions, there are still areas in the country where wind power generation is feasible. The mean average wind speed in Nigeria varies between 2 m/s to 6 m/s during the dry season and 15 m/s to 25 m/s during the rainy season. The average wind speed ranges between 2.7 m/s to 5.4 m/s depending on the location [15, 19-21].

RESs have been suggested for use as an alternative source of energy for rural electrification in Nigeria by many researchers [22-25]. These researches proposed the use of both single RES [11, 25-27] and hybrid RES [13, 23, 28-30]. Single RES requires the use of a single source for energy generation while the hybrid RES is the combination of two or more RES for energy generation. Based on the RES available in Nigeria, solar and wind energy are the most exploited sources of energy, this makes RES off-grid systems suitable for application in Nigeria. To achieve an optimal system, hybridizing two or more of these RESs is adopted and for maximum efficiency of the system, the combination of the RESs and a diesel generator becomes more effective due to fluctuations in weather condition. Various configurations have been considered in the hybrid RES which includes solar-wind-battery [23, 30-32], solar-wind-battery-diesel [22, 28, 33-35], etc. These configurations all proved feasible in the selected areas they were applied.

This study carries out a feasibility study on the use of a hybrid PV-wind-battery with a backup generator for rural electrification. Although there are lots of studies carried out in Nigeria to access the feasibility study of using hybrid RES, there are still areas where these studies have not been carried out. This study focuses on the northwestern part of Nigeria where there is abundant wind and solar energy that can be harnessed for rural electrification. The meteorological data used for this study is obtained from the NASA website and the feasibility study is carried out using the Hybrid Optimization Model for Electric Renewable (HOMER) Pro software. The HOMER Pro software does the optimization and comes up with the optimal configuration of the RES used for the study.

This paper is organized as follows; Section II briefly describes the study area and its RES potentials, Section III gives the system description which includes the load profile, the RES data, battery data, and generator data. Section IV describes the hybrid system modeling and its operational strategy while Section V presents the results and discussions and finally Section VI gives the concluding remarks.

2. Materials and Methods

This study investigates the economic feasibility analysis of using hybrid renewable energy system (HRES) based electricity generation for a rural community in Nigeria. A village is chosen in Moriki, Nigeria. The variables used for the optimization are the solar PV, wind turbine, generator, and batteries. HOMER optimization software was used for the system analysis. The software allows the designer to evaluate the alternative configuration and design based on the technical and economic merits of the components, mostly by means of comparative analysis. The study location, optimization software and the RES used for the study are discussed as follows.

2.1 Study location

The location selected for this study is in Zurmi local government area of Zamfara state, Nigeria. The location is located at latitude 12°52' N and longitude 6°29' E as presented in figure 1. The village is characterized to be blessed with abundant solar and wind energy sources. Table 1 presents the clearness index and solar radiation profile of the study area as generated by HOMER. It has average solar radiation of 6.01 KWh/m²/day and average sunshine hours of 7 hours/day. Table 2 presents the monthly average wind speed of the study area as obtained from NASA with an average wind speed of 3.60 m/s.

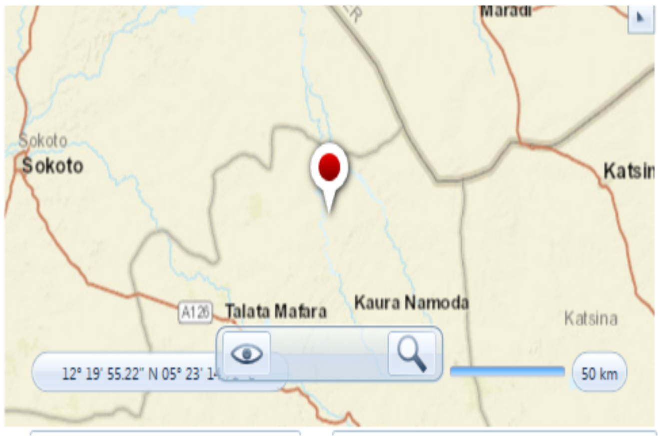

Figure 1. Map showing the study location

2.2 Solar potential

The availability of abundant solar energy in the village influenced the choice of photovoltaic (PV) power supply in the area. The people of Moriki village are mostly farmers and a few traders. Data of Moriki village obtained from NASA via HOMER software shows that it has an average solar irradiance of 6.01 KW/h/m²/day over 22 years which ranges between 5.25 to 6.84 KWh/m2/day as presented in Figure 2. The highest solar irradiance is obtained in the month of April and the least are in the month of December which is normally winter and August which is during the rainy season. With these recorded solar irradiances, it is evident that solar energy can be exploited for an off-grid system in Moriki village. Table 1 presents the monthly average solar irradiance and clearness index of the study area over 22 years.

Table 1. Average solar radiation, clearness index, and wind speed profile

Month	Clearness Index	Wind Speed (m/s)	Solar Radiation (KWh/m²/day)
January	0.648	3.750	5.500
February	0.679	3.610	6.290
March	0.665	4.130	6.700
April	0.648	4.110	6.840
May	0.632	4.090	6.700
June	0.618	3.550	6.500
July	0.540	3.380	5.680
August	0.505	3.170	5.310
September	0.562	2.830	5.730
October	0.628	3.000	5.940
November	0.658	3.540	5.680
December	0.640	3.970	5.250

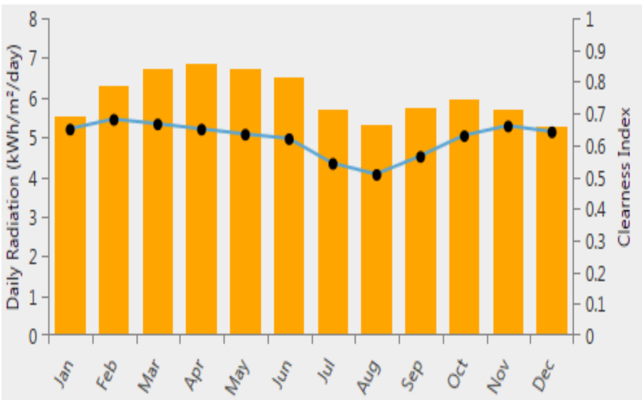

Figure 2. Solar radiation and clearness index

2.3 Wind resources

The wind speed data of Moriki village was also obtained from the NASA website via HOMER software. The wind data were recorded at about 10m and 50m respectively. The average wind speed of Moriki town over 25 years at 10m is 4.49 m/s and 7.27 m/s at 50m. The wind speed rises between 2.42 m/s to 4.94 m/s at 10m, with the least wind speed recorded during the month of September and the highest recorded during the month of January. Similarly, at 50m height, the wind speed recorded ranges between 3.79 m/s to 7.41 m/s recording the least in the month of September and the highest in the month of January. Figure 3 presents the wind speed variations according to the months of the year while Table 1 presents the monthly average wind speed of the study location. The wind speed obtained indicates that Moriki village has the required wind speed for wind power generation. From [36] wind power operation is normally between 2.5 m/s cut-in speed and 25 m/s cut-out speed.

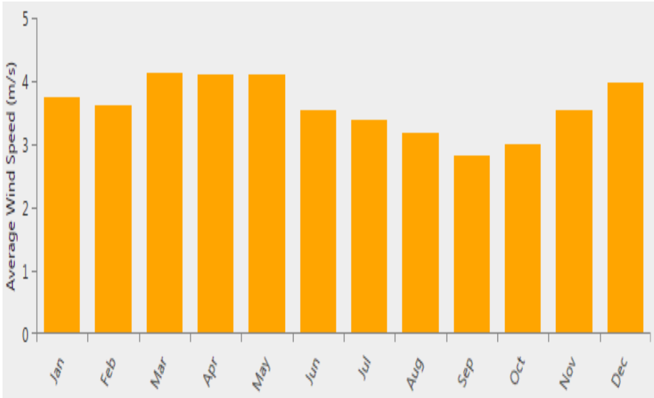

Figure 3. Wind speed variation throughout the year

2.4 Diesel generator

Diesel price is currently high in Nigeria with an average price of N270.00 ($0.75 at $1=N360). The price of diesel increases with an increase in crude oil price and decreases with a decrease in crude oil price. There may be an additional cost of transporting the diesel to the rural area which results in rising diesel price to about $1 per liter.

***2.5** HOMER software*

There are various software used for feasibility analysis of energy generation systems. Some of this software includes RETScreen, iHOGA, Hybrid 2 and HOMER software. For this study, HOMER software has been selected to perform the feasibility analysis due to its exceptional functions. HOMER software was designed by National Renewable Energy Research Laboratory (NERL) for the optimization of grid-connected and standalone renewable energy systems. One major advantage of HOMER software is the performance of major tasks of optimization, simulation, and sensitivity analysis [28, 37]. The functions of HOMER are shown in Figure 4.

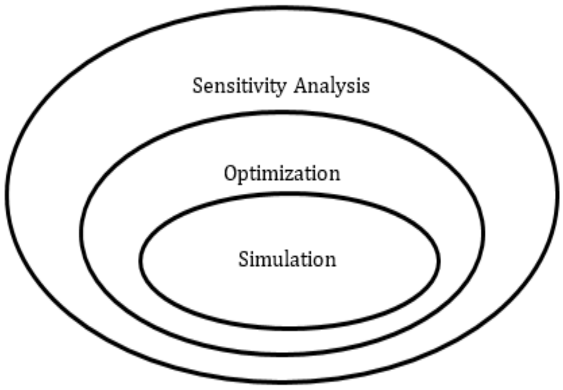

Figure 4. HOMER software functions

During the simulation process, the HOMER model measures the performance of the components of the proposed HRES based on hourly basis. This is done to obtain the best matching between the supply and the load demand, it also determines the techno-economic feasibility of the proposed HRES configuration. During the optimization process, the software creates a certain number of possible feasible systems according to the least NPC. This is also done by simulating the system configuration in order to choose the configuration that will meet the load demand at a minimal life-cycle cost and satisfy the technical constraint.

HOMER software utilizes various sources of renewable energy such as hydro turbines, wind turbines, photovoltaic, diesel and fuel cells. The simulation is carried out using inputs like load profile, meteorological data, components data, system economics, and technical constraints. The output of the HOMER software are the Net present cost (NPC) [38], Total Capital Cost (TCC), fuel consumption, Cost of Energy (COE), excess energy, renewable fraction (RF), and optimal system configuration that determines the best suitable configuration[39].

3. System Description

This section describes the load profile of the secondary school used for the study, the PV components data, wind components data, the battery, and the generator.

3.1 Load profile

The load profile of a secondary school in Moriki village is used as a case study. The secondary school consists of electrical appliances such as desktop computer, printer, lighting, fans and a fridge. The design considers the entire load of the school. Table 2 presents the load demand of the school as well as the load calculation to obtain the daily maximum consumption. The load demand is approximately 13.56 kWh/day with a peak load of 3.05 kW at a load factor of 0.19. The load data is then fed into the HOMER software to obtain the graphical representation of the hourly and monthly load profiles as presented in figures 5&6. The load profile shows that the peak load is in the afternoon during school hours which is 3.05 kW and the scaled annual average load is 13.56 kW.

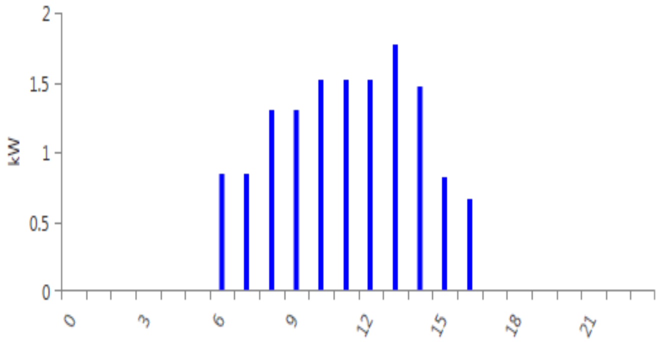

Figure 5. Hourly Load Profile

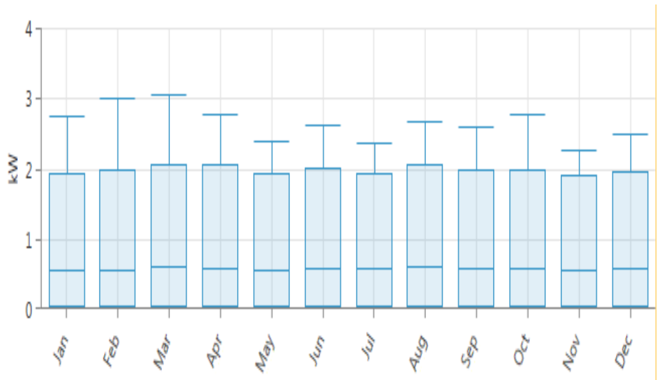

Figure 6. Monthly Load Profile

3.2 The PV data specifications

The technical data of the PV used for this study is presented in Table 3 and the cost parameters is presented in Table 5. The derating factor and the lifetime of the PV used are 90% and 25 years respectively. The yearly energy contribution of the PV panel is 7,388 kWh/year. The sizes of solar PV considered for this study is between 0 to 20 kW.

Table 2. Estimated electricity demand for a rural secondary school

Load description	No. in use	Power (W)	Operation hour (hr/day)	Total (W/day)
Ceiling fan	22	30	7	4,620
Lighting	42	20	4	3,360
Television	2	80	8	1,280
Fridge	1	300	6	1,800
Printer	1	250	2	500
Desktop computer	2	200	5	2,000
Total energy consumed				13,560

Table 3. Technical specifications of the generic flat plate solar PV

Parameter	Value	Units
Rated capacity	4	kW
Mean output	0.843	kW
Mean output per day	20.2	kWh/day
Capacity factor	21.1	%
Total production	7,388	kWh/year

3.3 Wind turbine specifications

The wind turbine technical parameters used for this study is shown in Table 4 and the cost parameters are presented in Table 5. The wind turbine used for this study is a generic 1 kW wind turbine. The wind speed characteristics versus wind power curve is plotted by HOMER software and presented in Figure 7. The hub height of the wind turbine is taken to be 17m and a lifetime of 20 years is considered for the wind turbine.

Table 4. Technical parameters of the generic 1kW wind turbine

Parameter	Value	Units
Rated capacity	1	kW
Mean output	0.0197	kW
Maximum output	0.796	kW
Capacity factor	1.97	%
Total production	172	kWh/year

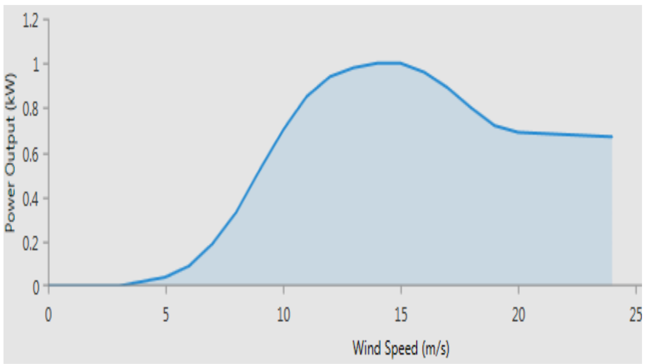

Figure 7. Wind power versus wind speed characteristics curve

3.4 Diesel generator specifications

The diesel generator used for this study is the generic 10 kW fixed capacity genset. The initial cost and replacement cost of this generator is presented in table 5. The maximum load ratio of the generator is 10% and has 15000 hours lifetime operation. The fuel efficiency versus output power curve is shown in Figure 8 and the considered size of diesel generator for this study is 0 to 10 kW.

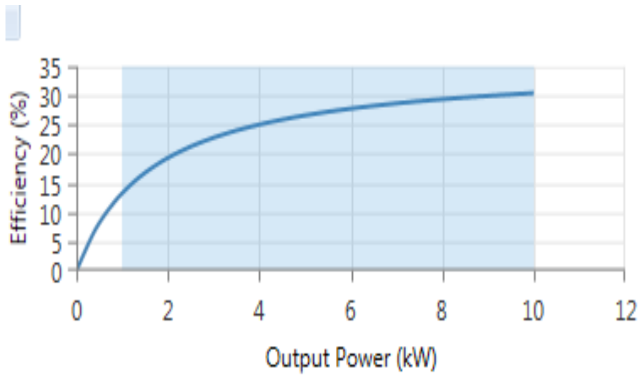

Figure 8. Diesel generator fuel efficiency curve

3.5 Battery specifications

The battery used in this study is Surrette 6CS25P battery with 224 Ah, 6 V, 1.35 kWh capacity. The system consists of 2 strings of batteries in parallel comprising of 8 batteries per string to give a 48 V bus. The unit size consideration of the battery is 0 to 160 with a round trip efficiency of 80% with a minimum state of charge (SOC) of 40%. The battery has a life span of 12 years, it has a lifetime throughput of 11660 kWh with a nominal capacity of 111kWh and autonomy of 117 hours. The battery cost is presented in Table 5.

3.6 Converter specifications

The converter used in this study is a 5 kW inverter with 100% rectifier relative capacity and 85% rectifier efficiency. It has a lifespan of 15 years and 90% inverter efficiency. The cost specifications of the converter are presented in Table 5, the size of the converter used for the study is from 0 to 20 kW at an interval of 5 kW.

Table 5. Hybrid system components' data

Parameter	Value	Units
	Solar PV	
Ground reflection	20	%
Capital cost/kW	3000	$
Replacement cost/kW	2500	$
O&M cost	0	$
Lifetime	25	Years
	Wind Turbine	
Capital cost/kW	6500	$
Replacement cost/kW	6000	$
O&M cost	70	$
Lifetime	20	Years
	Converter	
Capital cost/kW	300	$

Replacement cost/kW	300	$
O&M cost	50	$
Lifetime	15	Years
Efficiency	90	%
Rectifier efficiency	85	%
	Battery	
Initial cost	130	$
Replacement cost	130	$
O&M cost	0	$
Round trip efficiency	80	%
Battery string	8	
Lifetime	12	Years
Minimum state of charge	40	%
	Diesel Generator	
Capital cost/kW	4000	$
Replacement cost/kW	4000	$
O&M cost/hr	0.030	$
Lifetime	15000	Hours
Maximum load ratio	10	%

4. Hybrid Energy System Modeling and Energy Management Strategy

The hybrid system considered for this study combines solar PV panels, wind turbine generators, battery and backup generator [40]. The hybrid system is described in Figure 7. The hybrid system comprises of solar, wind, battery and backup generator. The system modeling and energy management strategy are discussed in this section.

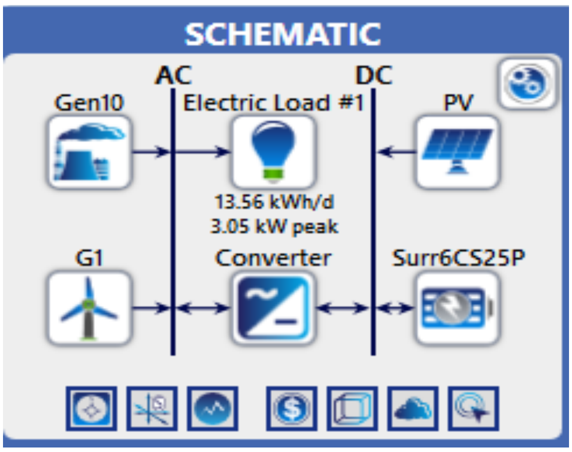

Figure 9. Hybrid solar-wind-battery-diesel system

4.1 Wind Turbine Model

The wind turbine power is generated through a mechanical process, the wind blows the blades which turn the generator of the wind turbine thereby producing electrical energy. The wind turbine power is calculated using equation (1) [41].

$$P_m = {}^{1}\!/_{2}\, \rho A C_p {V_w}^3 \qquad (1)$$

where Cp is the power coefficient, A is the swept area ρ is air density and Vw is the wind speed.

The power extracted at wind speed and at a time t is calculated using equation (2)

$$P_w(t) = \begin{cases} 0 & V < V_{cut-in}, V > V_{cut-out} \\ N_w V^3 a - P_{rate} b & V_{cut-in,} < V < V_{rate} \\ N_w P_{rate} & V_{rate} < V < V_{cut-out} \end{cases} \qquad (2)$$

a and b are constants and are given by the following equations

$$a = \frac{P_{rate}}{V^3{}_{rate} - V^3{}_{cut-in}}, \quad b = \frac{V^3{}_{cut-in}}{V^3{}_{rate} - V^3{}_{cut-in}} \qquad (3)$$

Where, N_w is the number of wind turbines, P_{rate} is the rated power, V is the hourly wind speed, $V_{cut-in,}$ V_{rate}, and $V_{cut-out}$ are the cut-in, rated and cut-out wind speed respectively.

4.2 Modeling solar PV

A solar system consists of solar panels connected in series or parallel for power generation. The output power generated by these panels is given in equation (4) [42].

$$P_{pv-out} = P_{pv-rated} \times \left({}^{G}\!/_{G_{ref}}\right) \times [1 + K_T(T_C - T_{ref})] \qquad (4)$$

where the output power of the PV cells is P_{pv-out}, the rated power at a reference condition is $P_{pv-rated}$, the solar radiation is given as G (W/m2) and the solar radiation at a standard temperature is G_{ref} (G_{ref}=1000W/m2). T_{ref} (25◦C) is the temperature of the cell at standard condition. The temperature coefficient is given as K_T, Tc is the ambient temperature.

4.3 Battery modeling

The battery is used as a storage system in the system design, it stores energy that may be used when the RES is not supplying energy due to climatic condition. Solar irradiance is not available to supply the load at night and there may be needed to avoid the use of the backup generator, the energy stored by the battery is then used to supply the load. This depends on the state of charge (SOC) of the battery, the capacity of the battery and the rate of charge and discharge of the battery. The battery storage capacity is given in equation (5) [43].

$$C_{wh} = {}^{(E_L \times AD)}\!/_{(\eta_{inv} \times \eta_{Batt} \times DOD)} \qquad (5)$$

where DOD is the battery depth of charge, the battery and inverter efficiency are η_{Batt} and η_{inv}, AD is the days of autonomy, $E_L$is the daily average load energy.

4.4 Diesel generator modeling

The diesel generator is used to increase the efficiency of the hybrid system in cases where the climatic condition is unfavorable and the battery does not have enough energy to supply the load. The performance is usually characterized by the generator efficiency, its fuel consumption and the type of fuel used. The fuel consumption is normally determined by the type of fuel used. Equation (6) represents the linear model of a DG set hourly fuel consumption [44].

$$F(t) = aP_{Rdg} + bP_{DG}(t) \quad (6)$$

where P_{Rdg} is the rated DG power, $P_{DG}(t)$ is the actual power generated by the DG at a time t. a and b are constants for the DG in liter/kW and they depend on the DG rated capacity.

4.5 Power management strategy

The operation strategy is in a such a way that during normal operation, the energy generated by the RES (PV and wind) is used to serve the load and when the energy generated exceeds the load demand, the remaining energy is used to charge the batteries to 100% charge. Excess energy from these sources will be directed to the dump load. During peak load, if the RES generation cannot supply the load demand, the generator will automatically start and supply the load, but the generator does not charge the battery.

5. Simulation Results

The meteorological data comprising of wind speed, solar radiation, and temperature coupled with the components data were input into the HOMER software model. It takes a couple of minutes to perform the simulation and come up with an optimal feasible configuration. The optimization is done in a way that the load requirement is met at the lowest cost of energy. The configurations suggested are based on the NPC, COE, Initial cost and operating cost. The PV-battery configuration is the best configuration for the selected location based on COE and NPC. The best configurations are further discussed below.

The PV-Battery hybrid system consists of a 4kW solar PV panels and 16 batteries comprising of two strings connected in parallel and a 5 kW converter. The COE of this system is $0.233/kWh and a total NPC of $18,161. The initial capital cost of the hybrid system is $15,580 with the PV system costing about 77% of the initial capital cost while the battery and converter contribute 13.4% and 9.6% respectively. The electricity supplied by this hybrid system is 100% renewable with zero emission. The excess electricity is 29.6% which is 2,389 kWh/year.

The PV-Diesel-Battery system is the second best configuration with 4kW solar PV panels, 10 kW diesel generator, 16 batteries, and a 5kW converter. The system has an NPC of $21,670 and COE of $0.278/kWh. The initial cost of the hybrid system is $20,580 with the PV panel contributing 58.3% of the initial cost, diesel generator 24.3%, while the battery and the converter contribute 10.1% and 7.3% respectively. The renewable fraction remains 100% with zero emission because the generator is not used throughout the year.

The PV-Wind-Battery configuration system consists of a 1 kW generic wind turbine with 4 kW solar PV panels, 16 batteries, and a 5 kW converter. The NPC of this hybrid system has increased to $26,823 and the initial capital cost has also increased to $22,080 due to the high cost of a wind turbine. The COE of this system is $0.344/kWh which has increased compared to the previous configurations.

The PV-Wind-Diesel hybrid system comprises of a 4 kW solar PV panels, 1 kW generic wind turbine, and a diesel generator. The initial capital cost of the system is $21,080 and an NPC of $29,225. The COE of the system has increased to $0.375/kWh. The system has an excess electricity of 31.5% which is 2,608 kWh/year. The solar PV supplies 97.7% of the total electricity produced while the wind turbine supplies only 2.3% of the total energy.

5.1 Sensitivity analysis

The sensitivity analysis for this study was carried out in order to analyze the influence of variation in the input parameter values on the COE and NPC. The wind speed, solar radiation, and nominal discount rates were used for the variations. After varying these parameters, it was observed that decrease in nominal discount rate and increase in wind speed and solar radiation decreases then the rate of COE and NPC, while an increase in nominal discount rate and a decrease in wind speed and solar radiation increases the rate of COE and NPC. It was also observed that solar radiation has more impact on the COE and NPC because of its availability in abundant quantity in the study area. Table 6 presents the results of the sensitivity analysis in terms of COE, NPC and Initial capital cost. The values highlighted in red indicates the effect of low wind speed, low solar radiation, and high nominal discount rate, while the ones highlighted in blue indicates the effect of high wind speed, high solar radiation and low nominal discount rate.

Table 6. Sensitivity cases in terms of NPC, COE and Initial cost

Solar Scaled Average (KWh/m²/day)	**Wind Scaled Average (m/s)**	**Nominal Discount Rate (%)**	**NPC ($)**	**COE ($)**	**Initial Capital ($)**
5.50	3.50	10	17,243	0.322	15,580
5.00	3.00	10	20,146	0.376	17,660
6.00	4.00	10	17,243	0.322	15,580
6.50	4.50	10	17,243	0.322	15,580
5.50	3.50	12	16,928	0.371	15,580

5.00	3.00	12	19,666	0.431	17,660
6.00	4.00	12	16,928	0.371	15,580
6.50	4.50	12	16,928	0.371	15,580
5.50	3.50	6	18,161	0.233	15,580
5.00	3.00	6	21,541	0.276	17,660
6.00	4.00	6	18,161	0.233	15,580
6.50	4.50	6	18,161	0.233	15,580
5.50	3.50	8	17,646	0.276	15,580
5.00	3.00	8	20,758	0.324	17,660
6.00	4.00	8	17,646	0.276	15,580
6.50	4.50	8	17,646	0.276	15,580

5.2 Discussion

Feasibility study of a hybrid solar-wind-battery-diesel system is carried out for a rural school in Moriki village, Nigeria. Four optimal configurations comprising of PV-Battery, PV-Diesel-Battery, PV-Wind-Battery, and PV-Wind-Diesel were the best configurations optimized by HOMER software in terms of COE and NPC. Table 7 presents the optimal results of various configurations with the least COE of $0.233/kWh and NPC of $18,161. The system that provides the optimal result is the PV-Battery hybrid system because of high percentage of solar energy in the selected location. The result also illustrates that the PV-Wind-Diesel hybrid system has high COE and NPC due to the high cost of diesel and wind turbine compared to the cost of solar panels. It is also observed that the hybrid RES satisfied the entire electric load of the school and it is powered by 100% renewables.

Table 7. Various systems configuration performance evaluation

configurations	**PV-Battery**	**PV-Diesel-battery**	**PV-Wind-Battery**	**PV-Wind-Diesel-Battery**
PV (kW)	4	4	4	2
Wind turbine(kw)			1	1
Gen set (kw)		10		10
Battery	16	16	16	16
Converter (kW)	5	5	5	5
NPC ($)	18,161	21,671	26,824	29,225
COE ($)	0.233	0.278	0.344	0.375
Initial cost ($)	15,580	20,580	22,080	22,080
Operating cost	163.87	69.23	301.15	517.04

6. Conclusions

This study presents an economic feasibility study of a stand-alone hybrid solar-wind-battery-system for a rural secondary school with no access to the national grid. The school has an electrical load of 13.56 kWh/day with a peak load of 3.05 kW, the project is designed to be 25 years. HOMER Pro optimization software was used to simulate and come up with the optimal configurations. The configurations provide very clean energy with zero emission and powered by 100% renewable energy. The optimal configuration of the system has a cost of energy of $0.233/kWh and the net present cost of $18,161, this is the most economically feasible solution simulated by HOMER. Sensitivity analysis is carried out by varying the nominal discount rate, wind speed, and solar radiation, the results show the effect of change of nominal discount rate, wind speed and solar radiation affect the system in terms of COE and NPC. From the results obtained, it proves the feasibility of setting up a stand-alone hybrid RES for electrifying the rural schools and the community at large.

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