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Feasibility of Harnessing Renewable Energy at an Off-grid Community in Nigeria

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Abstract— Due to high cost of fuel and fluctuating oil prices, integrating renewable energy into an existing diesel power system seems economical in the long run in meeting the load demand of off-grid rural settlements. This study analyzed the prospects of utilizing renewable energy resources in an off-grid remote community in Nigeria. Two scenarios were considered in this study using the HOMER (Hybrid Optimization Model for Electric Renewable) software; the diesel-only system and the diesel-wind-PV system. Economic parameters of NPC (net present cost) and COE (cost of energy) were used to compare these scenarios to determine the viability, feasibility and the most cost effective approach. The result shows that at the current diesel price of £0.67/L, it is feasible to utilize renewable energy in the community, and that despite the high initial installation cost of renewable components, the diesel-only system is about 1.3 times more expensive than the diesel-wind-PV system, making it quite an expensive option to continuously rely upon.

Index Terms— Net present cost, Diesel generator, Renewable Energy, HOMER software.

1 Introduction

The role of energy in the socio-economic development of any nation cannot be overemphasized owing to the fact that it is the mainstay for civilization, growth, security and a powerful tool for any industrial society. The usefulness of energy in our everyday activities is evident in the domestic human consumption in buildings; such as lighting, heating, cooking, washing, drying, to automobiles in transportation; land, sea and air transport systems, light and heavy equipment in industries; petroleum, chemical, mechanical and manufacturing industries, and the list goes on. Despite its importance, it is alarming that about 1.4 billion people, an equivalent of over 20% of the world's population do not have access to electrical energy in terms of electricity [11]. A further breakdown shows that the greatest challenge emanates from sub-Saharan Africa in which only 31% of its population have access to electricity supply, and that those in urban areas dominate that percentage [11]. Nigeria is not an exception and falls within such category.

With a population of over 150 million [8], the country's generation still fluctuates between 3200 MW and 4000 MW of electricity. In 2010, in order to meet the vision 2020 target of increasing electricity supply to carter for a substantial amount of household and industrial demands, it was estimated that the country needed US$ 3.5 billion annually over the next 10 years to achieve an estimated grid capacity of 40,000 MW [20]. Four years down the lane, there is minimal or no improvement to show for it. Rather, it was envisaged that by December 2014, there would be an increased capacity to 4500 MW generation, which is still a far cry from the initially expected estimate. However, this target was not met as a result of gas pipeline vandalism, poor maintenance of existing power plants, fluctuations in water levels, as well as decaying transmission and/or distribution infrastructure. In spite of several efforts made by the government through the power sector reforms to reintegrate Nigeria into a global economy through foreign direct investment [20] by unbundling of the Power Holding Company of Nigeria (PHCN) to give room for private sector investment in the areas of electricity generation, transmission and distribution, and setting up the Nigerian Electricity Regulatory Commission (NERC) as a body to independently regulate for embedded generation, distribution networks, customer service standards as well as tariff pricing and rating, these unfortunate situations have largely contributed to frequent power outages and epileptic supply thereby impairing economic growth and development.

Off-grid locations, especially the rural areas, are the most affected. Majority still live without electricity meanwhile the country is blessed with abundant natural resources; fossil fuels (oil, natural gas and coal) and renewable (hydro, wind and solar). Most of these remote communities run on diesel generator- set which is quite expensive to service and maintain due to high cost of fuel consumption, coupled with the high cost of running it on continuous bases. The rural electrification project currently on, has however not yielded the desired outcome because some of these communities are miles away from the national grid, in addition to high investment cost needed to set up substations, extended electrical lines and line losses during transmission [2]. It is expected that harnessing the available renewable energy in their domain if feasible and viable, in line with the Kyoto Protocol, will not only improve the economic activities of the inhabitants of these communities, but also improve their health and well being since concerns have been raised worldwide on dwindling fossil fuel reserves and global warming caused by green house gas emissions as a result of energy generation through conventional means [19, 26].

Several authors globally have carried out research on the technical feasibility and economic viability of harnessing renewable energy resources in different locations. Results have been achieved on both stand-alone and grid-connected configurations in small and large hotels, residential buildings, tourist centers and off-grid communities. Dalton et al. [10] carried out a feasibility study on the viability of a stand-alone

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renewable energy system to supply electricity to a large hotel with over 100 beds, annual consumption of 5.5 GWh and 966 kW of peak load in Queensland, Australia. The authors made use of the HOMER simulation software to compare renewable energy supply only, diesel generator-only and both renewable energy sources (RES)/diesel hybrid, basing their comparison on renewable fraction, net present cost and payback time. During their simulation, the monthly average wind speed had a variation of 4 m/s to 6 m/s while the solar irradiance varied between 3.4 kWh/m²/day and 6 kWh/m²/day. They concluded that the stand-alone renewable system (hybrid wind/solar) can meet the energy demand of the hotel. Similarly, [5] carried out a techno-economic assessment of an off-grid hybrid PV/diesel power system (450 kWh/day) that was installed in a bungalow building in Crete, Greece. They reported that at the grid electricity prices then, such configuration was not economically viable. Bekele and Palm [6] performed a feasibility study to investigate the possibility of supplying electricity to 200 families in a remote area in Ethiopia using PV/wind hybrid system and applying HOMER for both sensitivity and optimization analysis. They concluded that with 51% utilization of renewable energy, the system had a 19% increase in cost when compared to generator-battery-converter system. Shaahid et al. [25] did an analysis on the technical and economic potential of hybrid wind/PV/diesel power system to meet the energy demand of 15,945 MW in Rawdhat Bin Habas village in Saudi Arabia. They found out that the levelized cost of energy (COE) of the hybrid system was 0.118 $/kWh with the COE increasing with increasing penetration of the hybrid system.

In the home front, works have been done by indigenous researchers on the prospects of harnessing the available renewable energy mostly from solar, wind and hydro resources. Onyebuchi [17] estimated that Nigeria has the potential of harnessing 15.0 x 10 ^{14} kJ of useful solar energy amounting to about 4.2 x10^{5} GW/h of electricity production annually using a 5% device conversion efficiency. Similarly, [9] in corroboration to [23] showed that the solar energy potential of the country is vast with solar radiation varying between 3.5 kWh/m²/day and 7.0 kWh/m²/day with an annual average estimated to be 5.25 kWh/m²/day. Though the intensity of solar radiation reaching the earth surface varies with location, it is estimated that the country receives an average of about 6.5 hours of sunshine which will result to an average annual solar intensity of 1,934.5 kWh/m²/year [18].

On exploring the available wind energy resources in the country, [3] carried out a hypothetical feasibility analysis of integrating renewable systems in a rural health clinic in Borno State, Nigeria. With an energy consumption of 19 kWh/day and a peak demand of 3.4 kW, the average annual mean speed was determined to be 3.8 m/s. This is in conformity with wind speed variation in the country which is between 1.5 to 4.0 m/s [1, 24]. Despite the nation being blessed with abundant wind resources to generate electricity especially in mountains' surrounded communities in the northern part and offshore locations in the Niger delta region, harnessing of this energy is still lacking.

This study is on the feasibility of utilizing renewable energy resources to meet the load demand of a hypothetical rural community in Bayelsa State, Nigeria, while aiming to reduce the fuel consumption of the already existing diesel generator. HOMER will be used for this purpose. It will focus on the prospects of harnessing renewable energy and the possibility of using these resources to meet the load demand of the community while analyzing the energy systems in terms of stand-alone and hybrid configurations (diesel-only and hybrid diesel/RES) that will provide the most economically viable solution when using net present cost (NPC) and cost of energy (COE) as basis for comparison.

The rest of the paper is organized in this format: Section 2 will give an overview of the community. Next, section 3 will describe the system design. Section 4 gives a description of HOMER software and assessment criteria. Input parameters (technical, meteorological and economic) will be described in section 5. Then, Section 6 will depict the system dispatch strategy. Section 7 present results and discussion. Lastly, section 8 will provide a conclusion for the paper.

2 Overview Of The Community

The community is a rural settlement in close proximity to Oporoma (a town in Bayelsa State) in the oil rich Niger Delta region of Nigeria. The region is well known for oil exploration and exploitation activities of different multinational firms. Electricity supply in most of the coastal areas in this region, including Oporomo and the hypothetical community under study, is mainly by diesel generator causing a substantial amount of emission of pollutants and other green house gases leading to adverse environmental and health effects on the inhabitants. The rural electrification project, which is expected to connect these communities to the already existing grid, has experienced setbacks over time. These setbacks are as a result of the geographical location (mainly dominated by seas and oceans), other technical and economic obstacles such as inaccessible road network to carter for electrical infrastructure (substations, transmission lines) and the lack of political will of previous government. These factors have made it difficult to connect these remote sites to the existing national grid which in turn makes it challenging to meet the energy need of these low populated and isolated areas. Alternatively, renewable energy supply stands to be a good option in not just meeting the electrical needs of this populace, but provides a means of mitigating the hazardous effect of burning fossil fuels. It is also understood that a mix of renewable energy and conventional energy resources, when combined, will result in optimization of power generation systems both technically and environmentally, in addition to the economic impact in which there will be continuous and stable supply, coupled with reduction in operation and maintenance cost of diesel generators [22].

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3 System Design Description

The system will comprise of wind energy conversion systems (WECS) or wind turbines to harness wind energy, PV modules, diesel generator, storage batteries and power converters. Two different scenarios or case studies will be considered to determine the most economical and cost effective approach, while meeting the electricity demand of the community. Scenario 1 will be the use of diesel generator only and scenario 2 will be a hybrid system of diesel generator and renewable energy resources. The renewable energy resources to be considered will be restricted to wind and solar. A schematic diagram of the hybrid energy system with the diesel generator, wind turbine and other components is shown in Fig. 1.

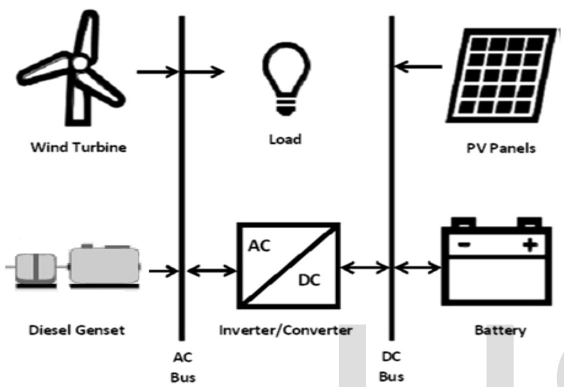

Fig. 1. Schematic of the system

4 Homer Simulation Software

4.1 Description of the Software

HOMER, an acronym for Hybrid Optimization Model for Electric Renewable, is software developed by the United States National Renewable Energy Laboratory (NREL) of the Department of Energy. According to [12] and [13], it is fundamentally an optimization software tool which simulates numerous system arrangements and scales same on the basis of NPC. It evaluates design options for both grid-connected and off-grid (stand-alone) systems. It initially makes an estimate of a system's ability to ascertain the technical feasibility of the system, i.e., confirming if the RES can satisfactorily serve both the electrical and thermal loads in addition to any possible constraints. Furthermore, HOMER estimates the system's economic viability through NPC (comprising of the system's initial capital cost, replacement cost of components during its lifecycle, the component cost of the system in terms of operation and maintenance and also the cost of fuel)[27]. For instance, in a year's operation, an hourly time-step simulation is performed on a specific system by its modeling activities. During each time-step, the renewable power available is calculated and compared to the electrical load requirement in either the building or site in which the study is carried out. Any excess electricity will be stored in a battery or in the case of a grid-connected system, will be sent to the grid once the RES fulfils the load demand required [10].

Input parameters into HOMER include electrical load data, data of renewable energy sources (photovoltaic and wind), cost and specification of the system's components, and optimization information of the model. The system configuration that has the lowest NPC after satisfying the constraint of the user is deemed the optimal configuration.

4.2 Evaluation Assessment Criteria

This section discusses indicators such as net present cost (NPC) and levelized cost of energy (COE).

4.2.1 Net Present Cost

The NPC is the summation of all cost within the lifespan of the project such as initial set-up cost of the system's components (IC), any other replacement cost (RC) that may occur, the operational and maintenance cost (OM) and the fuel cost over the project lifespan [10].

HOMER calculates the NPC using the relationship below [21]:

$$NPC(\$) = \frac{TAC}{CRF} \quad (1)$$

where TAC is the total annualized cost ($) and it is the sum of all annualized cost of each system component. CRF is the capital recovery factor and is given by:

$$CRF(\$) = \frac{i(1+i)^N}{(1+i)^N-1} \quad (2)$$

where N is the number of years and 'i' is the annual real interest rate (%).

4.2.2 Levelized Cost of Energy

This is the average cost per kilowatt hour of useful electrical energy produced by the system [16]. It is expressed by [14]:

$$COE = \frac{C_{tot}}{E_{tot}} \quad (3)$$

where

C_{tot} is the total annualized cost of the system ($/year)

E_{tot} is the total electricity consumption per year (kWh/year).

5 Input Parameters

5.1 Load Profile of the Hypothetical Community

In studies which have no known load profile, proposing a realistic user load is one of the most important steps in achieving a desired result when considering real life scenarios. Electricity consumption in rural areas is mainly for domestic usage in residential buildings (lighting, entertainment), agricultural activities (irrigation pump), community activities (town hall meetings, rural clinics, schools) and small-scale industrial activities (refrigeration, cassava processing plants and cottage industries).

A carefully estimated electricity load requirement will be proposed for use. A sample of 40 houses used for only residential purpose will be analyzed. In managing the daily affairs of occupants, typical rural electricity consumption will be determined to form the load profile. Electricity usage will include lighting of fluorescent lamp, multimedia such as TV and radio sets, electric iron, ceiling or table fans, air conditioners, fridges (refrigerators), and other electrical equipment. Other sources of usage; washing machine, microwave (or electric stove for cooking) will not be considered in this study as depicted in Table 1. Furthermore, the sizes and nature of the houses (4-bedroom duplex, 3-bedroom bungalow, single rooms etc), the number of occupants in each house, behavioral characteristics, user patterns and their exact activity schedules, are not considered in detail but are assumed where necessary. Worthy of note is that all appliances are assumed not to be used simultaneously except in few cases, but at various times or stages over a 24 h period during the daily consumption as seen in Fig. 2. HOMER then synthesizes 8760 hourly electrical load value for one complete year using the load profile in addition to random variables such as day-to-day and time-step-to-time-step. During the simulation process, in making the synthetic load data more practically oriented, day-to-day randomness and time-step-to-time-step randomness of 20% and 15% were respectively chosen.

TABLE 1
CONSUMPTION APPLIANCES

Load usage	Electrical power consumption (W)
TV	100
Radio	30
Electric iron	1000
Ceiling fan	30
Air conditioner	750
Refrigerator	100
Lighting	50
Other low energy equipment	40

5.1.1 Certain Assumptions in Determining the Electric Load

The following assumptions are made to determine the load profile of the community:

1. Out of the 40 houses in this study, 5 have one air conditioner (A/C) each. This A/Cs operates for approximately 8 h daily.
2. 5 of the houses with A/Cs have ceiling fans operating simultaneously with the A/Cs and 20 other houses without A/Cs do have ceiling fans operating at approximately 12 h.
3. 10 of the houses have refrigerators operating for 20 h except on certain weekends in which maintenance is needed (refilling of refrigerant).
4. 15 of the houses have TV sets operating for 8 h.
5. 20 of the houses have radio sets. 15 of those houses are without TV sets and they operate for 8 h while the remaining 5 belongs to the category of those with TV sets and operate for 4 h.
6. All the houses have fluorescent lamps which operate for 8 h.
7. Other low energy consumption equipments (handsets) are found in all 40 houses and operate for 4 h.
8. Electric iron is used by 25 houses for approximately 1 h daily.
9. As part of the cooperate social responsibility of the multinational oil firm operating within (onshore and offshore) the community, the diesel generator-set provided by the firm operates for 20 h daily.

Based on the above assumptions, the energy demand of the hypothetical community can be seen in the daily load profile diagram depicted in Fig. 2. The average daily electricity consumption of the 40 sampled houses as simulated by the software is 118.53 kWh/d with a peak demand of 30.9 kW and load factor of 0.16.

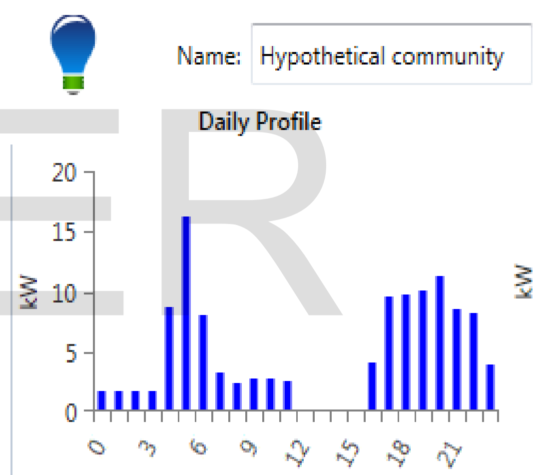

Fig. 2. Daily load profile of the 40 sampled houses

The peak demand occurred between 05:00 and 06:00 h. During this period, most of the daily activities are optimal, especially ironing of clothes. Consumption was slow at night, picked up between 04:00 and 05:00 h, got to the peak, and then slowed down towards mid-day. Between 12:00 and 16:00 h, when most of the occupants have gone out to carter for their daily needs, the diesel generator is put off. This interval is also used for refueling the generator tank. As some occupants gradually go back to their various houses, the generator is put on at 16:00 h, consumption picks up gradually, increases between 17:00 and 21:00 h, gradually slows till mid-night, and the cycle continuous.

5.2 Meteorological Data

Several authors [4, 7, 14] have used meteorological data obtained from the database of the Surface Meteorology and Energy website of the National Aeronautics and Space

Administration (NASA) [15]. The same source was adopted for this study. Data for Oporoma was used due to its close proximity to the hypothetical community, and therefore it is believed to have similar climatic conditions.

5.2.1 Solar Radiation

Solar radiation values for Oporoma (latitude 4º 48′North, longitude 6 º 4'East) as earlier said, was obtained from NASA website. This is a 22-year monthly solar radiation data as depicted in Fig. 3. The clearness index which is automatically generated once the daily radiation data is entered can be seen on the right axis as provided by HOMER. The solar radiation ranges between 5.49 kWh/m²/day and 6.65 kWh/m²/day with average clearness index of 0.615 and a scaled annual average of solar radiation estimated to be 5.67 kWh/m²/day. It is observed that solar radiation is high for the months of March to October, except in June, where there was a slight drop due to seasonal variations.

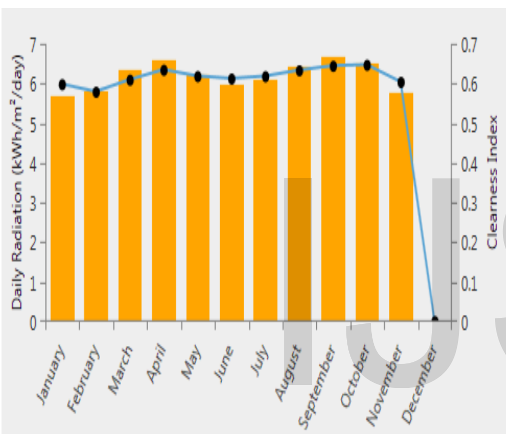

Fig. 3. Solar radiation data

5.2.2 Wind Speed

The wind speed data was also obtained from the same NASA website. This is the 10-year average monthly wind speed and was measured at 10 m above the surface of the earth in the interval of 3 h as seen in Fig. 4. It is suffice to say that 10 m height is basically applied in most standard measurements as 2 m height measurements are prone to error due to vegetation, shading and obstacles within the area of focus [7]. The monthly annual average wind speed is 2.95 m/s and wind speed ranges from 2.27 m/s to 3.98 m/s. The highest wind speed occurred between July and September; fairly good wind between December and February, and June and October; and the lowest in April and May. Both the wind and solar systems will compensate for one another throughout the calendar year due to their seasonal availability.

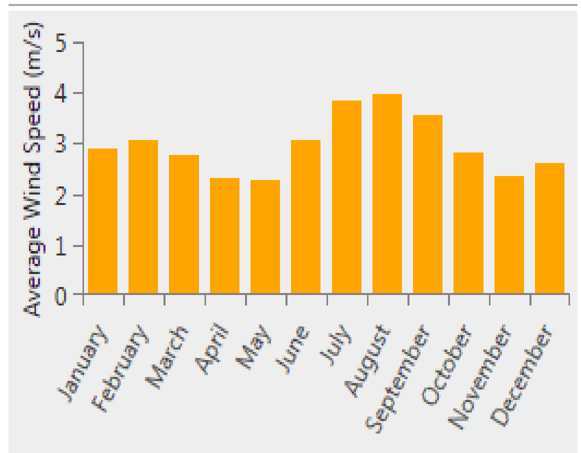

Fig. 4. Wind speed data

5.3 System Components, Cost and Design Specification

In other to compute the cost of components to match with real scenarios, an estimated factor of 1.3, which accounts for the purchase costs, import taxes and cost of transportation to the community has been multiplied by the purchase price of each component to determine the final cost used in performing the simulation as can be noticed when the price of diesel was dealt with in the section that followed.

5.3.1 Diesel Generator

In selecting a generator for a study like this, it is practically advisable to choose one that will cover for peak demand. In this study, the peak load demand is 30.9 kW and a generator with capacity of 36 kW was selected. The generator is manufactured by Cummins and operates with a 4-cylinder turbocharged engine at 1500 RPM. The cost and other specifications of the generator can be found in Table 2. In addition, the price of diesel in Nigeria when the study was carried out was ₦149 per liter in urban areas, but due to transportation and other cost associated in transferring it to remote areas, with an estimated factor of 1.3, the price was pegged at ₦194 per liter. Based on an exchange rate of ₦290 to £1, the pound equivalent will be £0.67 per liter. It is suffice to know that due to global market values and variations between countries, the price of diesel does not remain stagnant but fluctuates. Refer to Fig. 6 for the resultant fuel curve for the diesel generator.

5.3.2 Photovoltaic (PV) Modules

Based on market survey and open literatures, the capital cost of 1 kW of PV module is £5000. This includes all associated costs linked with the PV module such as mounting hardware, wiring and installation. The PV arrays taken into account were 0 (that is no PV), 10, 20, 30, 40 and 50 kW so as to examine the financial costing impact of the hybrid system. Please refer to Table 2 for further specifications of the PV component.

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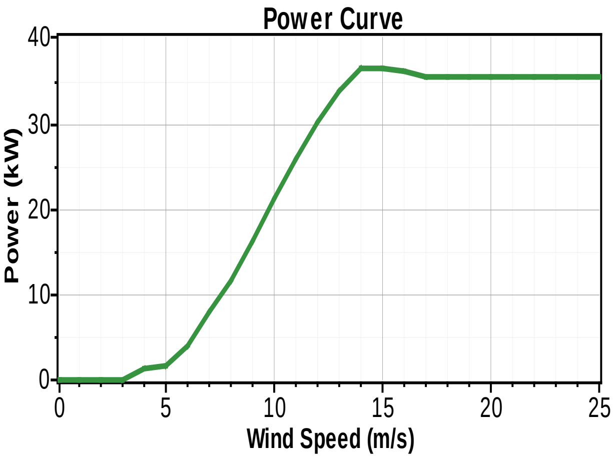

Fig. 5. PGE 35 wind turbine power curve

5.3.3 Wind Turbine

As a simple rule, it is expected that the wind turbine should be able to meet the peak demand. Therefore, the rating should be generally higher than the peak load. The wind turbine selected for this study is the PGE 35 model manufactured by Energie PGE and rated 35 kW. Three options were considered for optimum solution during the analysis; 0 (no wind turbine), 1 wind turbine and 2 wind turbines. See Fig. 5 for the wind turbine curve and Table 2 for other specifications of the wind turbine.

TABLE 2
TECHNICAL AND ECONOMIC DATA FOR THE COMPONENTS

Description	Data
Diesel generator	
Model	4BT3.9-G2
Rated power	36 kW
Capital cost (£/kW)	6300
Replacement cost (£/kW)	6300
Operation and maintenance cost (£/h)	0.03
Operating lifetime	15,000 h
Diesel fuel price (£/liter)	0.67
Photovoltaic modules	
Rated capacity	1 kW
Installation or capital cost (£/kW)	5000
Replacement cost (£/kW)	5000
Operating & Maintenance cost (£/kW/yr)	10
Derating factor (%)	80
Efficiency at standard test condition	13%
Sizes of PV	0, 10, 20, 30, 40 & 50 kW
Lifetime	20 years
Wind turbines	
Model	PGE 35
Rated power	35 kW
Installation or capital cost (£)	20000
Replacement cost (£)	18000
Operating & Maintenance cost (£/yr)	150
Lifetime	15 years
Number of units considered	0, 1 and 2
Storage battery	
Model	Surrette 6CS25P
Capital cost (£)	1000
Replacement cost (£)	1000
Operating & maintenance cost (£/yr)	10
Float-life	12 years
Sizes considered	0, 10, 20, 30, 40 & 50.
Power converter	
Rated capacity	1 kW
Capital cost (£)	1000
Replacement cost (£)	1000
Operating & maintenance cost (£/kW/yr)	10
Efficiency	90%
Lifetime	15 years
Sizes varied	0, 5, 10, 15 & 20 kW

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5.3.4 Storage Battery

The battery selected for this study is the Surrette 6CS25P manufactured by Rolls/Surrette firm. It has a nominal capacity and voltage of 1156 Ah and 6 V respectively. One battery alone has 6.94 kWh of energy stored which will result to producing 27.76 kWh of electricity if four batteries are used. The battery has a bank of 12 units of battery; a 6-stings total with two batteries for each sting. Please refer to Table 2 for other properties of the battery.

5.3.5 Power Converter

The converter chosen for this study has a rating of 1 kW with capital and replacement cost of £1000 each. The size variations of the converter are 0, 5, 10, 15 and 20 kW. See Table 2 for other details of the converter.

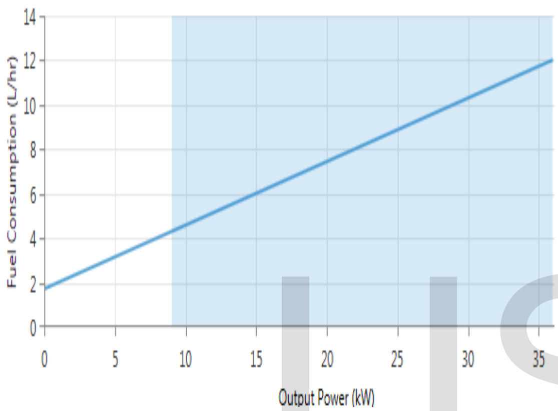


Fig. 6. Fuel curve of the diesel generator

6 Dispatch Strategy

This deals with basic principles involved in charging of the battery bank in the system. In stand-alone cases where electricity is supplied by hundred percent renewable, this rule is irrelevant since the battery will be charged by the surplus renewable energy. On the other hand, for systems that consist of both battery bank and diesel generator, it is necessary to consider the operation of the system on how the diesel generator will charge the battery bank. In this study, the dispatch strategy chosen is the cycle charging. The strategy involves a running generator operating at full capacity and charges the batteries with the surplus energy. During the operation, the battery minimum state of charge (SOC) parameter (which is 40%) will stimulate the generator to start at the SOC. A set-point SOC of 80% was selected for this study to enable the generator continue charging the battery bank until it reaches the chosen set-point SOC.

7 Results and Discussion

Based on the input parameters in section 5, a simulation was performed with annual real interest rate of 6%, project lifespan of 20 years and capacity shortage fraction of 2%. Furthermore, operating reserve of 10% was selected for load reserve, 25% and 50% were respectively selected for PV power output and wind energy reserve. Two scenarios were simulated by HOMER in comparing the optimal configuration of the entire system. The first scenario is a base case in which electricity supply was solely from diesel generator and the second is a hybrid/RES configuration (diesel-wind-PV).

7.1 Diesel-only System

The diesel-only system with a 36 kW generator was found to be uneconomical when compared to the diesel-wind-PV configuration. The system as depicted in Fig. 7 has a total NPC of £351,091 and COE of £0.593/kWh based on fuel price of £0.67/L.

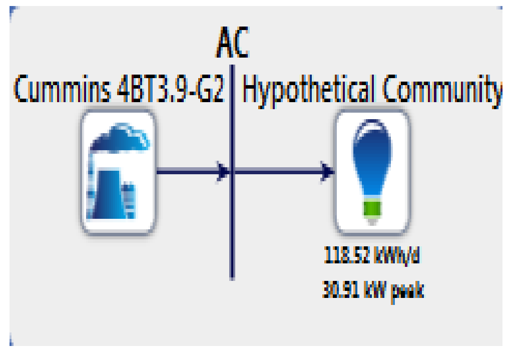
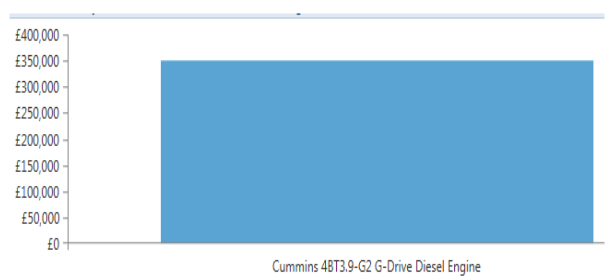


Fig. 7. Schematic of the diesel-only system

The generator operates for 7300 hours and uses 33,109 L of fuel to produce 71,655 kWh to satisfy the AC load of 43,260 kWh with an excess of 28,396 kWh (about 39.6%) energy produced in a year. The excess energy can still be utilized in other aspects such as water heating, water pumping and other refrigeration purposes.



Component	Capital (£)	Replacemen	O&M (£)	Fuel (£)	Salvage (£	Total (£)
Cummins 4BT3.9-G2 G-Drive Diesel Engine	£6,300.00	£38,990.00	£2,997.10	£303,582.00	-£778.39	£351,091.00
System	£6,300.00	£38,990.00	£2,997.10	£303,582.00	-£778.39	£351,091.00

Fig. 8. Cashflow summary for the diesel generator

During the operation, a total of 87,188 kg/yr of carbon dioxide was emitted to the atmosphere (Fig. 9). The combustion of fuel does not only lead to carbon dioxide emission, but produces other pollutants which are harmful to the environment and contributes to destruction of the ozone layer, green house effect and global warming. Based on [22], when there is release of a trillion tons of carbon into the

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atmosphere, a 2^{0}C peak warning is triggered. This poses an identified danger point in the atmosphere. In this regard, the world has to try as much as possible in keeping the carbon level below a trillion tons so as to reduce global warming effect.

Quantity	Value	Units
Carbon Dioxide	87,188.00	kg/yr
Carbon Monoxide	215.21	kg/yr
Unburned Hydrocarbons	23.84	kg/yr
Particulate Matter	16.22	kg/yr
Sulfur Dioxide	175.09	kg/yr
Nitrogen Oxides	1,920.30	kg/yr

Fig. 9. Greenhouse gas emission of the diesel-only system

The cash flow distribution of the system is shown in Fig.8. It can be seen that the cost of fuel consumption is the most expensive component (£303,582) followed by the replacement cost (£38,990). This acts as the main set-back in the diesel-only system where a lot of cash is expended on fuel to satisfy the load over the project lifespan. As a matter of fact, the cost of fuel is not stable but fluctuates. An increment will lead to increase in the total cost of the system and therefore increase in the COE which would relatively have an impact on the choice of the system.

7.2 Hybrid Diesel-Wind-PV System

The schematic diagram of the hybrid diesel-wind-PV configuration is shown in Fig. 10. The optimization result of the system is calculated by HOMER and ranked based on the NPC as shown in Table 3. As can be seen from the table, the highlighted portion shows the most economical configuration when both PV panel and wind turbine is added to the already existing diesel generator.

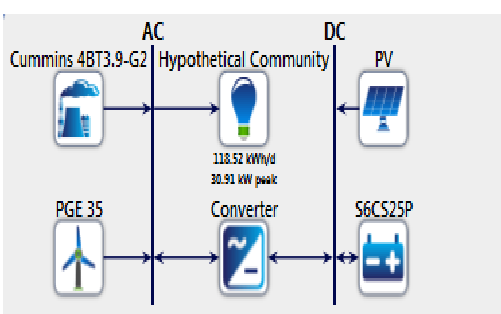

Fig. 10. Schematic of the hybrid diesel-wind-PV system

Energy analysis of the system shows that the combination of 36 kW Cummins 4BT3.9-G2 diesel generator, one unit of 10 kW PV array, one 35 kW PGE 35 wind turbine, 30 Surrette S6CS25P batteries and 10 kW converter yields an annual total energy production of 61,135 kWh/yr. Breakdown of this shows that the diesel generator contributes 32,160 kWh/yr, an equivalent of 52.6% of the total production, wind turbine generates 11,059 kWh/yr resulting to 18.1% of total production, and lastly 17,916 kWh/yr, an equivalent of 29.31% of the total production was the portion due the PV array. This system met the AC primary load of 43, 260 kWh/yr with 17.2% excess electricity. Renewable fraction of 25.7% was achieved by the introduction of solar and wind technology which ultimately reduced the excess electricity from 39.6% (diesel –only) to 17.2% (diesel-wind-PV).

The initial and operation costs are respectively £116,300 and £11,215. Also, the hours of operation of the diesel generator dropped from the initial 7300 hours to 1959 hours, thereby subsequently reducing the fuel consumption from 33,109 L (diesel-only) to 12,583 L (diesel-wind-PV) and cost of fuel from £303,520 to £115,374 as seen in Fig. 8 and Fig. 11 .

TABLE 3
OPTIMIZATION RESULT FOR THE HYBRID DIESEL-WIND-PV SYSTEM

Architecture							
PV (kW)	PGE 35 (qty)	Cummins 4BT3.9-G2 (kW)	S6CS25P (qty)	Converter (kW)	Dispatch	COE (£/kWh)	NPC (£)
	1	36	10	5	CC	£0.407	£240,887
		36	20	5	CC	£0.418	£247,579
10.0		36	10	5	CC	£0.436	£258,051
10.0	1	36	30	10	CC	£0.456	£269,780
		36			CC	£0.593	£351,091
	1	36			CC	£0.616	£364,907
10.0		36		5	CC	£0.623	£368,662
10.0	1	36		5	CC	£0.641	£379,616
60.0	2		50	20	CC	£0.803	£469,839

The system has a total net present cost (NPC) of £269,780 and COE of £0.456/ kWh. The NPC and COE values of this hybrid system are lower than the NPC and COE of the diesel-only system. As a matter of fact, by introducing solar and wind technology into the system, which to a large extent eliminated the high cost of fuel consumption, the NPC reduced significantly from £351,091 (diesel-only) to £269,780 (diesel-wind-PV), that is, a 23.16% reduction.

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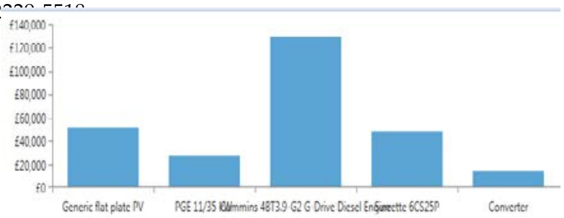

Component	Capital (£)	Replacemen	O&M (£)	Fuel (£)	Salvage (£)	Total (£)
Generic flat plate PV	£50,000.00	£0.00	£1,368.50	£0.00	£0.00	£51,369.00
PGE 11/35 kW	£20,000.00	£10,109.00	£2,052.80	£0.00	-£5,559.90	£26,601.00
Cummins 4BT3.9-G2 G-Drive Diesel Engine	£6,300.00	£8,188.20	£804.28	£115,374.00	-£1,132.60	£129,534.00
Surrette 6CS25P	£30,000.00	£18,908.00	£4,105.60	£0.00	-£4,633.30	£48,381.00
Converter	£10,000.00	£5,615.80	£1,368.50	£0.00	-£3,088.80	£13,896.00
System	£116,300.00	£42,821.00	£9,699.70	£115,374.00	-£14,415.00	£269,780.00

Fig. 11 Cash summary of the hybrid diesel-wind-PV system

Emission analysis (Fig. 12) shows that the system produces 33,135 kg/yr, 81.79 kg/yr, 9.06 kg/yr, 6.17 kg/yr, 66.54 kg/yr and 729.81 kg/yr respectively for carbon dioxide, carbon monoxide, unburned hydrocarbons, particulate matter, sulfur dioxide and nitrogen oxides. It will be noticed that the corresponding savings of pollutants emitted to the atmosphere are as follows; 54053 kg/yr for carbon dioxide, 133.42 kg/yr for carbon monoxide, 17.67 kg/yr for particulate matter, 108.55 kg/yr for sulfur dioxide and 1190.49 kg/yr for nitrogen oxide. This will improve the health of the inhabitants of the community and reduce associated medical bills.

Quantity	Value	Units
Carbon Dioxide	33,135.00	kg/yr
Carbon Monoxide	81.79	kg/yr
Unburned Hydrocarbons	9.06	kg/yr
Particulate Matter	6.17	kg/yr
Sulfur Dioxide	66.54	kg/yr
Nitrogen Oxides	729.81	kg/yr

Fig. 12. Greenhouse gas emission of the diesel-wind-PV system

One interesting result from Table 3 shows that it is possible to achieve a desired result without even integrating PV array to the system. This can actually be seen in the first row of the optimized result. The system comprise of the 36 kW Cummins 4BT3.9-G2 diesel generator, one 35 kW PGE 35 wind turbine, 10 Surrette S6CS25P batteries and one 5 kW converter. The NPC of the configuration is £240,887, that is, 31.3% reduction when compared to the diesel-only scenario. The initial and operating costs stood at £41,300 and £14,580 respectively. The system runs for 3554 hours, consumes 18,219 L of fuel and produces 53,287 kWh/yr to meet the AC load of 43, 280 kWh/yr. The generator contributes 70.25% while wind turbine generates 20.75% of the total production with a zero percent unmet load and 11.1% excess electricity during the process. The COE of the system is £0.407/ kWh with renewable contribution of 2.4% from the wind turbine. Emission analysis shows that the system emitted 47,976 kg/yr of carbon dioxide, 118.47 kg/yr of carbon monoxide and 1,056 kg/yr of nitrogen oxides. This amounts to approximately 45% reduction in the emission of these gases when compared to the diesel-only scenario.

7 Conclusion

This study attempted to explore the prospect of utilizing solar and wind technologies to reduce the use of fossil fuel to meet the load demand of an off-grid remote community in Bayelsa State, Nigeria. Two scenarios were considered during the simulation process. The first was the base scenario of using diesel generator solely to meet the load demand of the community (diesel-only system) and the second; the integration of solar and wind energy into the already existing system (diesel-wind-PV). COE and NPC were used as two major parameters to determine the most cost effective and economical approach. The simulation performed evidently indicated that despite the initial high investment cost of renewable energy components, the long time effect shows that it is more beneficial to integrate these resources into the existing diesel-only system. As a matter of fact, based on the NPC, at the current diesel price of £0.67/L, the diesel-only system is about 1.3 times more expensive than the diesel-wind-PV system, making it quite an expensive option to continuously embark on. It was also revealed that with renewable contribution of 47.4% (18.1% for wind and 29.3% for PV) to the total electricity production, the COE was found to be £0.456/kWh, about 23.1% reduction when compared to the base case scenario.

A further reduction of NPC and COE was found when during the simulation; HOMER optimized the result without including the PV arrays. As initially stated, the system has a 36 kW Cummins 4BT3.9-G2 diesel generator, one 35 kW PGE 35 wind turbine, 10 Surrette S6CS25P batteries and one 5 kW converter. The NPC of the configuration is £240,887, that is, 31.3% reduction when compared to the diesel-only scenario with a COE of £0.407/ kWh.

With the above studied scenarios, it is evident that much more can be gained when renewable energy integration is considered in the designing of power plants to meet different load profiles. Despite its high initial cost of installation, it is more economical sometimes, as in this case, and in all cases reduces the amount of emissions of pollutants into the atmosphere.

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