# Energy Optimization Map for Off-Grid Health Clinics in Nigeria

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**Abstract-** A model for the development of energy optimization map for health clinics was presented. This model was used to study three hypothetical off-grid remote health clinics at various geographical locations in Nigeria. These locations include: Nembe (Bayelsa State) in the south, Abaji (Abuja, FCT) in the centre, and Guzamala (Borno State) in the north. These were chosen to reflect the various climatic conditions in Nigeria. Hybrid optimization model for electric renewables (HOMER) software was used to design an optimal hybrid power system based on comparative economic and environmental analysis. Four different combinations (three hybrid power system options and a mix of renewable system) of three energy resources (solar photovoltaic (SPV), wind turbine generator (WTG), and diesel generator (DG)) were simulated and compared for each of the three selected health clinic locations. Optimization was conducted on each of the case study sets of data and results were generated. The findings of the study were organized and presented using tables. The developed energy optimization map shows that there is no generalized least-cost option for powering health clinics at different locations as this depends on climatic conditions and available renewable energy resources.

**Keywords-** Hybrid system, Health clinic, Climatic regions, Equatorial climate, Tropical climate, Arid climate, HOMER, Electricity Supply, Model.

## 1. Introduction

Power supply is a critical challenge the health services confront in setting up the health clinics and deploying their facilities (such as refrigerators and electronic diagnostic equipment) in rural areas. These facilities are part of the standard of care in rural clinics throughout the world. In the developed countries well-developed power infrastructure exists, whereas in the developing world the national electricity grid is always the energy solution of choice for powering health service facilities. The chances of delivering a constant power supply through the grids are not reliable and have limited coverage. This challenge is also applicable to a developing nation like Nigeria as most of its health clinics are located in the rural areas which are outside the reach of national grids and the electrification by grid extension would be expensive. From the above overview, it is evident that lack of grid power supply in rural Nigeria poses great challenges to all stakeholders in the health sector. To manage this challenge, health clinics in developing countries have to generate their own electricity. At present the problem of inadequate electricity supply experienced at the health clinics in Nigeria is being harnessed by using diesel generators. Little or no attention has been paid to the exploitation of all other available energy (renewable) resources in these rural areas. The operation and maintenance of diesel generators are relatively costly [1], and also pollutes the environment. Renewable energy is considered to contribute significantly to the reduction of this energy cost and emissions, if properly incorporated into the health clinic energy sources. Hybrid power systems (HPSs) have been identified as among the popular cost-saving renewable energy applications in the health sector. But till date these systems (HPSs) have found little or no applications in Nigeria. This may be attributed to the lack of information on the location and system parameters required to design suitable HPSs to meet given loads of health clinics. The work reported in this paper has been designed to explore the HPS potentials for powering rural clinics at various climatic regions of Nigeria. The research is based on modeling and simulation using the hybrid optimization model for electric renewables (HOMER) software. Specifically, this study sought to provide a model for producing energy optimization maps for health clinics in Nigeria, particularly in the rural off-grid area.

### 1.1. *Energy Optimization Model*

Energy optimization is described here as the process of assessing the energy load of any health clinic at a location and matching it with cost-effective and environmentally friendly power supply using theoretical models. This goal is followed by selecting the best components and their sizing, and finding the best available energy option (in terms of economic cost and environmental friendly) that will effectively power specific health clinics. The design of the most effective economic configuration from among a variety of options (diesel generators, PV arrays, wind turbines, etc.) signifies the selection of the best energy option available at the health clinic. The parameters useful for reaching the decision on the type of energy solution suitable for a health clinic and its location are grouped into the following:

- Total cost of energy generation, and;
- Total environmental impact of each energy solution

These two summarize all the factors proposed for evaluating the suitability of energy solution for any health clinic and location in Nigeria. The model for the development of energy optimization map for the health clinics in Nigeria is produced here in the figure below (figure 1).

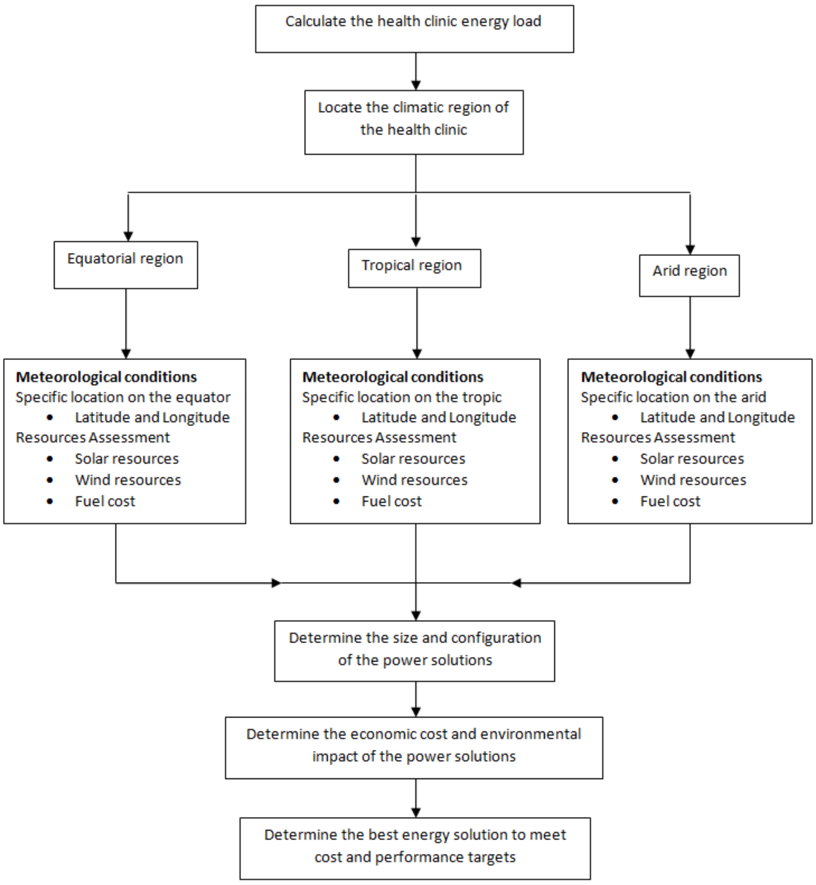


**Fig. 1.** Model for the development of energy optimization map for health clinics in Nigeria.

## 2. Power Consumption

A health clinic offers a wider array of services include the treatment of illnesses, the tending of injuries, basic emergencies, and the provision of basic immunization services. These services make use of medical devices, appliances, facility support functions, and sophisticated diagnoses equipment, that requires a reliable power supply. The energy demand is based on the type and number of medical devices used in the facility and the frequency with which they are used on a daily basis [2].

### 2.1. *A Reference Rural Health Clinic*

A standard rural health clinic in the Agbani district of Nkanu-West was used to create a profile for the rural health clinics in Nigeria. Figure 2 shows the daily profile electricity consumption of this clinic described by [2]. This health clinic (Agbani health clinic) has its average daily of 19 kWh per day. The electrical load data can be found in the appendix (A9). Obviously, many rural health clinics in Nigeria have the same electrical load data with that of Agbani which can be used in the establishment of a general case study for the electrical load data. The created profile (clinic loads) was used for the simulation.

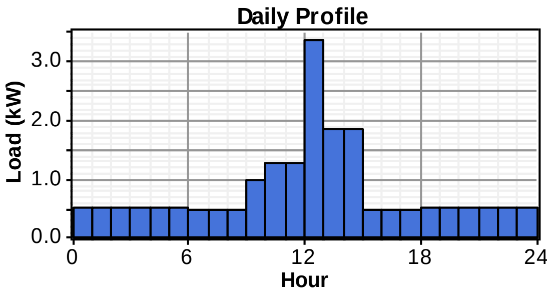


**Fig. 2.** Daily load profile of the health clinic [2].

## 3. Hypothetical Rural Health Clinic: The Case Study Sets of Locations in Nigeria

The locations of the hypothetical health clinic are chosen to reflect the various geographical and climatic conditions in Nigeria. Nigeria is divided into three main climatic regions: the equatorial climatic region where the global solar radiation ranges from 4.1 to 4.9 kWh/m$^2$/day, the tropical climatic region where the global solar energy is around 5kWh/m$^2$/day, and finally the arid climatic region where the global solar radiation is higher than 5kWh/m$^2$/day as can be seen in appendix A6, A7, and A8, respectively. The wind is characterized by a moderate speed (2.4 to 5.4m/s). The wind chart of Nigeria, figure. 3 is provided by [3].

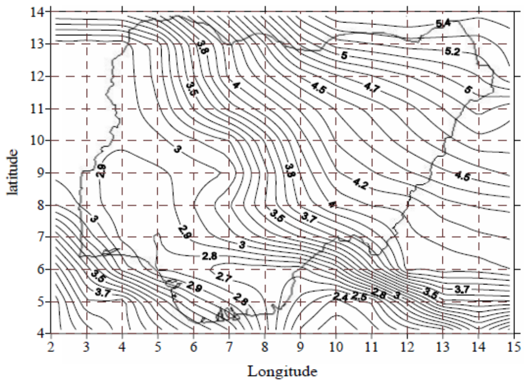


**Fig. 3.** Isovents of Average Daily Wind Speed at 50 m of Height above Earth

Surface across Nigeria [3].

These locations for the hypothetical health clinic are:

Nembe (Bayelsa State) in the equatorial climatic region

Abaji (Abuja, FCT) in the tropical climatic region

Guzamala (Borno State) in the arid climatic region; and these are indicated by red circles on the geographical map of Nigeria below (figure 4).

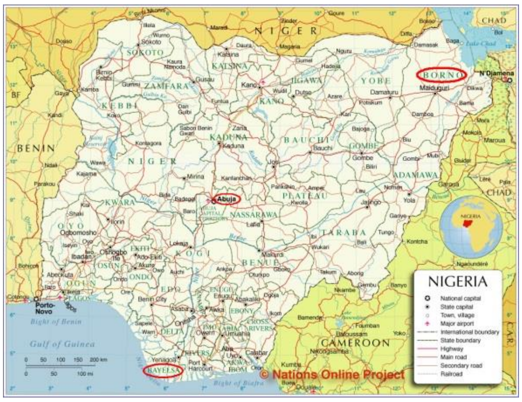


**Fig. 4.** Map of Health Clinic Locations on Study

### *3.1. Specific Locations and their Resources Assessment*

The availability of renewable energy system (RES) at a location differ considerably from location to location. This is a vital aspect in the development of the hybrid system. The performances of certain renewable energy components like solar and wind are influenced by the geographical location and climatic conditions [4]. As RES (solar and wind) are naturally available and intermittent, they are the best option to be combined into a hybridized diesel system. These resources (solar and wind) depend on different factors (such as the amount of solar energy available is dependent on climate and latitude, the wind resource is influenced by atmospheric circulation patterns and geographic aspects) in turn influences when and how much power can be generated and thus the behaviour and economics of the hybrid system. Moreover, weather data are important factors for pre-feasibility study of renewable hybrid energy system for any particular location (site) [5]. The data for monthly average solar radiation and wind speed for a given year (2012) were obtained from NASA [6].

The specific geographical locations (latitude and longitude) of the health clinic based on solar and wind resources are as follows:

- Nembe (Bayelsa State) at a location of 4° 17' N latitude and 6° 25' E longitude with annual average solar (clearness index and daily radiation) of 4.12kWh/m²/d whereas its annual average wind is 3.0m/s. Figures 5.1a and 5.1b show the solar and wind resource profile of this area.
- Abaji (Abuja, FCT) at a location of 9° 00' N latitude and 7° 00' E longitude with annual average solar daily radiation of 5.45 kWh/m²/d whereas its annual average wind is 2.4m/s. Figures 5.2a and 5.2b show the solar and wind resource profile of the location.
- Guzamala (Borno State) at a location of 11° 05' N latitude and 13° 00' E longitude with annual average solar (clearness index and daily radiation) of 5.90 kWh/m²/d whereas its annual average wind is 3.8m/s. Figures 5.3a and 5.3b show the solar and wind resource profile of this location.

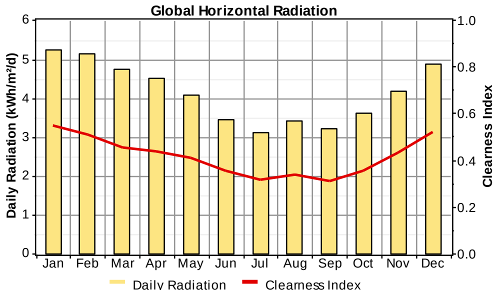


**Fig. 5.1a.** HOMER output graphic for Solar (clearness index and daily radiation) profile for Nembe

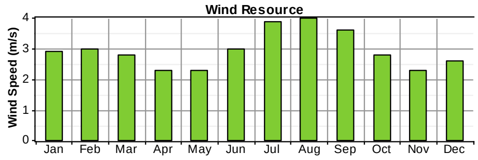


**Fig. 5.1b.** HOMER output graphic for Wind Speed profile for Nembe

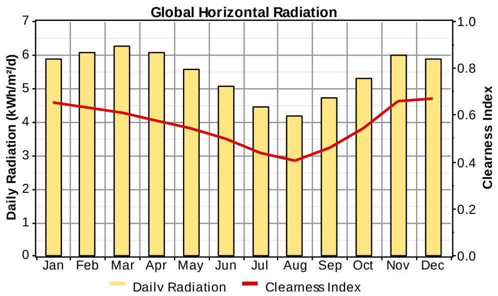


**Fig. 5.2a.** HOMER output graphic for Solar (clearness index and daily radiation) profile for Abaji

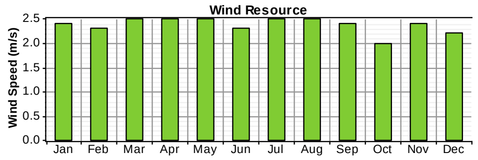


**Fig. 5.2b.** HOMER output graphic for Wind Speed profile for Abaji

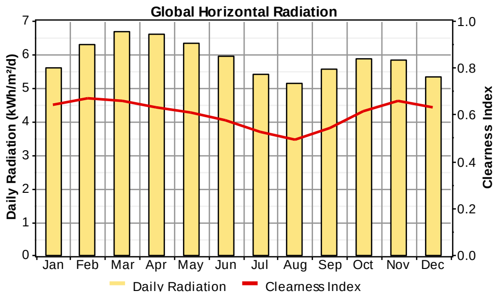


**Figure 5.3a.** HOMER output graphic for Solar (clearness index and daily radiation) profile in Guzamala.

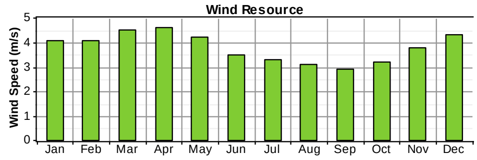


**Fig. 5.3b.** HOMER output graphic for Wind Speed profile in Guzamala.

## 4. Configuration of the Power System

The power systems are composed of PV panel, wind turbine, diesel generator, battery, and converter. A standard market prices of each component are shown in table 1. This provided the base input data for the simulation and optimization process. The fuel price is fixed to 1$/L for Nembe, 1.5$/L for Abaji and 1.8$/L for Guzamala. References to relevant literature provided the design guidelines. The network architecture (HOMER simulator) for the designed hybrid energy system of the health clinic centre is shown in figure 6. The designed power system for the health clinic composed of hybrid PV (5kW), BWC Excel-R wind turbine (7.5kW), diesel generator (2kW), 24 units Surrete 6CS25P battery and converter (19kW) system. The estimated lifetime of the project is 20 years. The interest rate is fixed at 6% annually. There is no capacity shortage for the system and operating reserve as a percentage of hourly load was 10%.

Meanwhile, the operating reserve as a percentage of solar power production and wind power output was 25% and 50% respectively. Operating reserve is the safety margin that helps ensure reliability of the supply despite variability in electric load, solar power supply and the wind power supply. The hybrid system components and their attributes are shown in the appendix (A1 – A5).

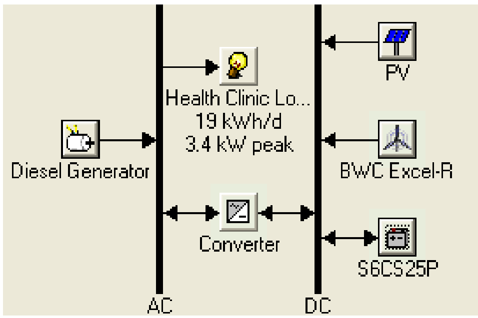


**Fig. 6.** The network architecture (HOMER simulator) for the hybrid energy system of the health clinic centre.

**Table 1.** Economic data (Initial System Costs, Replacement Costs and Operating & Maintenance Costs) of all the components of the hybrid system used in the Simulation

| Item | Initial System Costs | Replacement Costs | Operating & Maintenance Costs |
|---|---|---|---|
| PV modules | $2,000/kW | $1,800/kW | $1/yr |
| BWC Excel-R Wind turbine | $27,000 | $21,000 | $300/yr |
| 2kW Diesel Generator | $950/kW | $750/kW | $0.1/hr |
| Surrete 6CS25P battery | $1,145 | $1,000 | $200/yr |
| Converter | $200/kW | $200/kW | $4/yr |

## 5. Material and Method

HOMER software is the tool used for the simulation and optimization. The idea is to use the software (HOMER) to design an optimal system, since HOMER gives a knowledge of the optimal system amongst the feasible systems. During this simulation an attempt was made to determine for each climatic region and regarding the selected components, which of the mix renewable energy (PV/Wind/Battery) or hybrid system (PV/Wind/Diesel/Battery; PV/Diesel/Battery; Wind/Diesel/Battery) is the optimal power system. To obtain this optimal system, a few assumptions and restrictions have been made. Firstly, the BWC Excel-R 7.5kW wind turbine has not been modified, and the number of wind turbines in the system has been fixed at 1. Moreover, willing to keep all the different components within the system, the minimum power of each component is restricted to 2 kW. Finally, in order to favour the use of renewables over the use of the Diesel Generator, the Generator size has been limited to 2kW to match its energy production. This optimal sizing has been obtained step by step by modifying gradually the size of the different elements with the objectives to minimize their size for cost interests and to reduce as far as possible the use of the diesel generators for environmental interests. Renewable energy fraction exceeding 60% of the total energy supplied was used as the criteria for the energy map.

## 6. Results and Discussion

### *6.1. Results*

*Equatorial Region (Nembe)*

The components needed to satisfy the annual load of 7,082kWh are shown in figure 6. The optimal system found using HOMER is a hybrid PV/Diesel system (table 2) for the capital cost of $43,180 and the net present cost (NPC) which is the capital cost and the total cost of maintain this system with these components (PV/Diesel/Batt/Conv), would be $124,652 as shown in table 3. Renewable energy in this configuration (PV/Diesel hybrid system) represents 66% of the total energy production (table 2), the generator will be running about 1,578 hours per year corresponding to 1,039 diesel litres consumption as shown in tables 4 and 5, respectively.

The second option considered by HOMER in this region is a hybrid energy (PV/Wind/Diesel system) with 93% renewable energy penetration. Addition of wind turbine increased the NPC to $142,469 but reduces the running hour of the diesel generator (fuel consumption) thereby reduced the emission by 27%. The power system configurations (table 2) and their results (economic cost, electricity production, and environmental impact) are summarized in tables 3, 4, and 5.

**Table 2.** Power system configurations

| Configurations | PV | BWC Excel-R Wind turbine | Diesel Generation | Surrette 6CS25P Battery | Converter | Renewable fraction (%) |
|---|---|---|---|---|---|---|
| PV/Diesel/Batt/Conv | 5kW | | 2kW | 24 units | 19kW | 66* |
| PV/Wind/Diesel/Batt/Conv | 5kW | 7.5kW | 2kW | 24 units | 19kW | 93* |
| Diesel/Batt/Conv | | | 2kW | 24 units | 19kW | 0 |
| Wind/Diesel/Batt/Conv | | 7.5kW | 2kW | 24 units | 19kW | 36 |

*Significant renewable fraction exceeding 60%

**Table 3.** Simulation results of Economic cost

| Parameter | PV/Diesel/Batt/Conv | PV/Wind/Diesel/ Batt/Conv | Diesel/ Batt/Conv | Wind/Diesel/ Batt/Conv |
|---|---|---|---|---|
| Initial Cost | $43,180 | $70,180 | $33,180 | $60,180 |
| Operating Cost ($/yr) | 7,103 | 6,302 | 10,021 | 8,780 |
| Total NPC | $124,652 | $142,469 | $148,124 | $160,887 |

**Table 4.** Simulation results of Electricity production

| Parameter | PV/Diesel | PV/Wind/Diesel | Diesel | Wind/Diesel |
|---|---|---|---|---|
| PV | (6,220)<br>66% | (6,220)<br>60% | 0% | 0% |
| Wind | 0% | (3,385)<br>33% | 0% | (3,385)<br>36% |
| Diesel | (3,146)<br>34% | (750)<br>7% | (9,402)<br>100% | (6,112)<br>64% |
| Total | (9,366)<br>100% | (10,355)<br>100% | (9,402)<br>100% | (9,497)<br>100% |

**Table 5.** Simulation results of Environmental impact

| Parameter | PV/Diesel | PV/Wind/Diesel | Diesel | Wind/Diesel |
|---|---|---|---|---|
| Fuel Consumption (L) | 1,039 | 248 | 3,103 | 2,017 |
| Hour of diesel consumption (hrs) | 1,578 | 380 | 4,701 | 3,056 |
| Carbon dioxide (kg/yr) | 2,736 | 654 | 8,170 | 5,311 |
| Carbon monoxide (kg/yr) | 6.75 | 1.61 | 20.2 | 13.1 |
| Unburned hydrocarbon (kg/yr) | 0.748 | 0.179 | 2.23 | 1.45 |
| Particulate matter (kg/yr) | 0.509 | 0.122 | 1.52 | 0.988 |
| Sulphur dioxide (kg/yr) | 5.49 | 1.31 | 16.4 | 10.7 |
| Nitrogen oxides (kg/yr) | 60.3 | 14.4 | 180 | 117 |

*Tropical region (Abaji)*

The optimal hybrid power system proposed by HOMER is a hybrid PV/Diesel system. The components needed to satisfy the annual load of 7,082kWh are 5kW of PV, 2kW capacity generator, 24 unit batteries and 19kW converter as shown in table 6. The capital cost of this system is $43,180 and the NPC is $118,847. The renewable energy (RE) fraction represents 85% of the energy production (table 6). The generator will be running 764 hours and will use 500L/yr of diesel fuel as shown in table 9.

The second option considered by HOMER in this region is a hybrid energy (PV/Wind/Diesel system). Renewable energy in this configuration (PV/Diesel hybrid system) represents 94% of the total energy production. Addition of wind turbine increased the NPC to $142,925, but the running hour of the diesel generator is reduced to 311 hours per year corresponding to 203 diesel litres consumption thereby reduced the emission by 9%.

**Table 6.** Power system configurations

| Configurations | PV | BWC Excel-R Wind turbine | Diesel Generation | Surrette 6CS25P Battery | Converter | Renewable fraction (%) |
|---|---|---|---|---|---|---|
| PV/Diesel/Batt/Conv | 5kW | | 2kW | 24 units | 19kW | 85* |
| PV/Wind/Diesel/Batt/Conv | 5kW | 7.5kW | 2kW | 24 units | 19kW | 94* |
| Diesel/Batt/Conv | | | 2kW | 24 units | 19kW | 0 |
| Wind/Diesel/Batt/Conv | | 7.5kW | 2kW | 24 units | 19kW | 16 |

*Significant renewable fraction exceeding 60%

**Table 7.** Simulation results of Economic cost

| Parameter | PV/Diesel/ Batt/Conv | PV/Wind/Diesel/ Batt/Conv | Diesel/ Batt/Conv | Wind/Diesel/ Batt/Conv |
|---|---|---|---|---|
| Initial Cost | $43,180 | $70,180 | $33,180 | $60,180 |
| Operating Cost ($/yr) | 6,597 | 6,342 | 11,573 | 10,830 |
| Total NPC | $118,847 | $142,925 | $165,917 | $184,397 |

**Table 8.** Simulation results of Electricity production

| Parameter | PV/Diesel | PV/Wind/Diesel | Diesel | Wind/Diesel |
|---|---|---|---|---|
| PV | (8,493)<br>85% | (8,493)<br>80% | 0% | 0% |
| Wind | 0% | (1,502)<br>14% | 0% | (1,502)<br>16% |
| Diesel | (1,512)<br>15% | (614)<br>6% | (9,402)<br>100% | (7,756)<br>84% |
| Total | (10,005)<br>100% | (10,608)<br>100% | (9,402)<br>100% | (9,258)<br>100% |

**Table 9.** Simulation results of Environmental impact

| Parameter | PV/Diesel | PV/Wind/Diesel | Diesel | Wind/Diesel |
|---|---|---|---|---|
| Fuel Consumption (L) | 500 | 203 | 3,103 | 2,559 |
| Hour of diesel consumption (hrs) | 764 | 311 | 4,701 | 3,878 |
| Carbon dioxide (kg/yr) | 1,317 | 535 | 8,170 | 6,740 |
| Carbon monoxide (kg/yr) | 3.25 | 1.32 | 20.2 | 16.6 |
| Unburned hydrocarbon (kg/yr) | 0.36 | 0.146 | 2.23 | 1.84 |
| Particulate matter (kg/yr) | 0.245 | 0.0996 | 1.52 | 1.25 |
| Sulphur dioxide (kg/yr) | 2.65 | 1.07 | 16.4 | 13.5 |
| Nitrogen oxides (kg/yr) | 29 | 11.8 | 180 | 148 |

*Arid region (Guzamla)*

The optimal system found using HOMER is a hybrid PV/Diesel system for the capital cost of $43,180 and the NPC of $115,730 as shown in tables 10 and 11, respectively. Renewable energy in this configuration (PV/Diesel hybrid system) represents 91% of the total energy production, the generator will be running about 466 hours per year corresponding to 306 diesel litres consumption as shown in tables 12 and 13, respectively.

The second option considered by HOMER in this region is a pure renewable energy (PV/Wind system). The capital cost of this system is $68,280 and the NPC is $137,138. The renewable energy (RE) fraction represents 100% of the energy production (table 10). In terms of environmental impact, this system is environmentally friendly (has zero emission) as shown in table 13.

**Table 10.** Power system configurations

| Configurations | PV | BWC Excel-R Wind turbine | Diesel Generation | Surrette 6CS25P Battery | Converter | Renewable fraction (%) |
|---|---|---|---|---|---|---|
| PV/Diesel/Batt/Conv | 5kW | | 2kW | 24 units | 19kW | 91* |
| PV/Wind/Batt/Conv | 5kW | 7.5kW | | 24 units | 19kW | 100* |
| PV/Wind/Diesel/Batt/Conv | 5kW | 7.5kW | 2kW | 24 units | 19kW | 100* |
| Wind/Diesel/Batt/Conv | | 7.5kW | 2kW | 24 units | 19kW | 74* |
| Diesel/Batt/Conv | | | 2kW | 24 units | 19kW | 0 |

*Significant renewable fraction exceeding 60%

**Table 11.** Simulation results of Economic cost

| Parameter | PV/Diesel/ Batt/Conv | PV/Wind/ Batt/Conv | PV/Wind/Diesel/ Batt/Conv | Wind/Diesel/ Batt/Conv | Diesel/ Batt/Conv |
|---|---|---|---|---|---|
| Initial Cost | $43,180 | $68,280 | $70,180 | $60,180 | $33,180 |
| Operating Cost ($/yr) | 6,325 | 6,003 | 5,963 | 7,823 | 12,503 |
| Total NPC | $115,730 | $137,138 | $138,580 | $149,911 | $176,593 |

**Table 12.** Simulation results of Electricity production

| Parameter | PV/Diesel | PV/Wind | PV/Wind/Diesel | Wind/Diesel | Diesel |
|---|---|---|---|---|---|
| PV | (9,138) 91% | (9,138) 55% | (9,138) 55% | 0% | 0% |
| Wind | 0% | (7,490) 45% | (7,490) 45% | (7,490) 74% | 0% |
| Diesel | (925) 9% | 0% | 0% | (2,568) 26% | (9,402) 100% |
| Total | (10,062) 100% | (16,628) 100% | (16,628) 100% | (10,058) 100% | (9,402) 100% |

**Table 13.** Simulation results of Environmental impact

| Parameter | PV/Diesel | PV/Wind | PV/Wind/Diesel | Wind/Diesel | Diesel |
|---|---|---|---|---|---|
| Fuel Consumption (L) | 306 | 0 | 0 | 853 | 3,103 |
| Hour of diesel consumption (hrs) | 466 | 0 | 0 | 1,318 | 4,701 |
| Carbon dioxide (kg/yr) | 805 | 0 | 0 | 2,246 | 8,170 |
| Carbon monoxide (kg/yr) | 1.99 | 0 | 0 | 5.54 | 20.2 |
| Unburned hydrocarbon (kg/yr) | 0.22 | 0 | 0 | 0.614 | 2.23 |
| Particulate matter (kg/yr) | 0.15 | 0 | 0 | 0.418 | 1.52 |
| Sulphur dioxide (kg/yr) | 1.62 | 0 | 0 | 4.51 | 16.4 |
| Nitrogen oxides (kg/yr) | 17.7 | 0 | 0 | 49.5 | 180 |

## 7. Discussion

The hypothetical health clinic locations in Nembe, Abaji, and Guzamala has PV/Diesel as their optimal system. This system has the least NPC but higher emission than the PV/Wind/Diesel system.

On the other hand, PV/Wind/Diesel system is the best configuration in Nembe and Abaji in terms of emissions (has the lowest environmental impact), while for Guzamala PV/Wind configuration and PV/Wind/Diesel solution are very close in terms of emissions (zero emission).

Nembe and Abaji need the same PV/Wind/Diesel optimal combination but Abaji has more favourable meteorological conditions. That means relying less on the diesel generator (311 hrs/yr versus 380 hrs/yr for Nembe).

Guzamala has options of a mix of renewable energy (PV/Wind), and hybrid systems (PV/Wind/Diesel, and Wind/Diesel) as they exceed the 60% renewable fraction used as a criteria for the energy map.

In conclusion, based on the renewable fraction (RF) exceeding 60% of the total energy supplied, the following options were to be chosen from when setting up off-grid rural health clinic in Nigeria.

1. Equatorial Region has two options (PV/Diesel, and PV/Wind/Diesel)
2. Tropical Region has also two options (PV/Diesel, and PV/Wind/Diesel)

Arid Region has four options (PV/Diesel, PV/Wind, PV/Wind/Diesel, and Wind/Diesel)

## 8. Conclusion

The simulation results show that the percentage of energy generated by both the solar and the wind renewable energy components of each of the hybrid system types tends to vary with the locations of the health clinic. Both the NPC and the environmental impact of the hybrid energy system types studied vary significantly with the locations of the health clinics. Quantitatively, the hybrid power system is cost-effective and environmentally friendly in providing energy to health clinics than diesel generators. The proposed scheme is highly preferable for rural and remote areas where there are no grid connections. The developed energy optimization map shows that there is no generalized least-cost option for powering health clinics at different locations as this depends on climatic conditions and available renewable energy resources. This study proves that it is possible to produce an optimized energy map for health clinics in Nigeria.

I recommend for further study, the Research and Development of Energy Management System for the Hybrid PV/Wind/Diesel-Battery Power Systems for Rural Health Clinic.

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## Appendix

**Table A1.** Details of Solar Properties

| Solar Module type: SolarWorld SW 140 poly R6A | |
|---|---|
| Module Size (kW) | 0.140 |
| Array Size (kW) | 5.0 |
| Lifetime | 20 yr |
| Derating factor | 90% |
| Tracking system | No Tracking |

**Table A2.** Details of the Wind Parameters

| Wind Turbine type: BWC Excel-R | |
|---|---|
| Nominal Power (kW) | 7.5 |
| Quantities to Consider | 0, 1 |
| Lifetime | 20 yr |
| Weibull k | 2.00 |
| Wind shear profile | Logarithmic |

**Table A3.** The details of Diesel Generator model parameters.

| AC Generator type: 2kW Diesel Generator | |
|---|---|
| Size Considered (kW) | 2 |
| Quantity Considered | 1 |
| Lifetime | 20,000 hrs |
| Fuel used | Diesel |

**Table A4.** Surrette 6CS25P Battery Properties

| Battery type: Surrette 6CS25P | |
|---|---|
| Quantities to Consider | 24, 48 |
| Lifetime throughput | 9,645 kWh |
| Nominal capacity | 1,156 Ah |
| Nominal Voltage | 6 V |

**Table A5.** Details of Converter Parameters

| Converter | |
|---|---|
| Sizes to Consider (kW) | 0, 19 |
| Lifetime | 20 yr |
| Inverter efficiency | 85% |
| Inverter can parallel with AC generator | Yes |
| Rectifier relative capacity | 100% |
| Rectifier efficiency | 85% |

**Table A6.** Solar and wind Resources for Nembe (Bayelsa State).

| Month | Clearness Index | Average Radiation ($kWh/m^2/d$) | Wind speed (m/s) |
|---|---|---|---|
| **Jan** | 0.547 | 5.240 | 2.900 |
| **Feb** | 0.509 | 5.130 | 3.000 |
| **Mar** | 0.454 | 4.730 | 2.800 |
| **Apr** | 0.434 | 4.500 | 2.300 |
| **May** | 0.408 | 4.090 | 2.300 |
| **Jun** | 0.354 | 3.450 | 3.000 |
| **Jul** | 0.316 | 3.110 | 3.900 |
| **Aug** | 0.336 | 3.420 | 4.000 |
| **Sep** | 0.311 | 3.220 | 3.600 |
| **Oct** | 0.356 | 3.600 | 2.800 |
| **Nov** | 0.433 | 4.180 | 2.300 |
| **Dec** | 0.520 | 4.880 | 2.600 |
| **Scaled annual average** | | **4.124** | **2.960** |

**Table A7.** Solar and wind Resources for Abaji (Abuja, FCT).

| Month | Clearness Index | Average Radiation ($kWh/m^2/d$) | Wind speed (m/s) |
|---|---|---|---|
| **Jan** | 0.652 | 5.880 | 2.400 |
| **Feb** | 0.630 | 6.090 | 2.300 |
| **Mar** | 0.610 | 6.270 | 2.500 |
| **Apr** | 0.577 | 6.060 | 2.500 |
| **May** | 0.539 | 5.580 | 2.500 |
| **Jun** | 0.497 | 5.060 | 2.300 |
| **Jul** | 0.434 | 4.440 | 2.500 |
| **Aug** | 0.404 | 4.190 | 2.500 |
| **Sep** | 0.460 | 4.730 | 2.400 |
| **Oct** | 0.542 | 5.310 | 2.000 |
| **Nov** | 0.655 | 5.980 | 2.400 |
| **Dec** | 0.668 | 5.860 | 2.200 |
| **Scaled annual average** | | **5.449** | **2.375** |

**Table A8.** Solar and wind Resources for Guzamala (Borno State).

| Month | Clearness Index | Average Radiation ($kWh/m^2/d$) | Wind speed (m/s) |
|---|---|---|---|
| **Jan** | 0.642 | 5.610 | 4.100 |
| **Feb** | 0.666 | 6.300 | 4.100 |
| **Mar** | 0.658 | 6.700 | 4.500 |
| **Apr** | 0.628 | 6.620 | 4.600 |
| **May** | 0.606 | 6.360 | 4.200 |
| **Jun** | 0.576 | 5.970 | 3.500 |
| **Jul** | 0.523 | 5.430 | 3.300 |
| **Aug** | 0.492 | 5.140 | 3.100 |
| **Sep** | 0.544 | 5.570 | 2.900 |
| **Oct** | 0.612 | 5.890 | 3.200 |
| **Nov** | 0.658 | 5.840 | 3.800 |
| **Dec** | 0.631 | 5.350 | 4.300 |
| **Scaled annual average** | | **5.894** | **3.799** |

**Table A9.** The electrical load (Power supply requirements) data for a Health facility

| S/no | Power Consumption | Power (Watts) | Qty | Load (watt x qt) | Hours/day | On-Time (Time in Use) |
|---|---|---|---|---|---|---|
| **1** | Vaccine Refrigerator/Freezer | 60 | 1 | 60 | 24 | (0.00hr – 23.00hr) |
| **2** | Small Refrigerator (non-medical use) | 300 | 1 | 300 | 5 | (10.00hr – 15.00hr) |
| **3** | Centrifuge | 575 | 1 | 575 | 2 | (12.00hr – 14.00hr) |
| **4** | Hematology Mixer | 28 | 1 | 28 | 2 | (10.00hr – 12.00hr) |
| **5** | Microscope | 15 | 1 | 15 | 5 | (09.00hr – 14.00hr) |
| **6** | Security light | 10 | 4 | 40 | 12 | (18.00hr – 6.00hr) |
| **7** | Lighting | 10 | 2 | 20 | 7 | (09.00hr – 16.00hr) |
| **8** | Sterilizer Oven (Laboratory Autoclave) | 1,564 | 1 | 1,564 | 1 | (12.00hr – 13.00hr) |
| **9** | Incubator | 400 | 1 | 400 | 24 | (0.00hr – 23.00hr) |
| **10** | Water Bath | 1,000 | 1 | 1,000 | 1 | (14.00hr – 15.00hr) |
| | Communication via VHF Radio | | 1 | | | |
| **11** | Stand-by | 2 | | 2 | 24 | (0.00hr – 23.00hr) |
| **12** | Transmitting | 30 | | 30 | 4 | (09.00hr – 13.00hr) |
| **13** | Desktop Computer | 200 | 2 | 400 | 5 | (09.00hr – 14.00hr) |
| **14** | Printer | 65 | 1 | 65 | 3 | (09.00hr – 10.00hr; 13.00 – 15.00hr) |