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# Off-grid rural electrification using integrated renewable energy sources

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## ABSTRACT

Presented in this study is an economic and technical evaluation to determine the optimal system combination for off-grid power generation based on solar, wind and biodiesel renewable energy resource. Nsukka being endowed with high-intensity solar radiation, adequate wind speed and sufficient bioresource is a prospective candidate for a hybrid system. The monthly average daily global radiation ranges from 3.91 kWh/m$^2$ to 5.74 kWh/m$^2$ and the average wind speed is about 2.64 m/s. This system was designed to meet the load requirement of the school with annual electrical demand of 10,163 MWh. Sensitivity analysis was carried out based on the effect of change in biodiesel fuel price and interest rates on the economic performance criteria of the optimal configuration. The optimum hybrid system is composed of a 1 kW capacity PV system, an auto-sized biodiesel generator, and a battery bank of 820 h of autonomy. The levelized cost of energy from the optimal system was found to be $0.0898 per kWh based on sensitivity results. These results obtained shows that an integrated system with combination of PV, biodiesel generator and battery bank is a cost-effective alternative to grid extension which cost $0.126 per kWh. The system life span is for 25 years, and it is sustainable, economical, technically feasible and environmentally friendly.

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## 1. INTRODUCTION

In our world today, we have underrated the level of productivity and sustainability renewable energies would offer to human development. Renewable energy which is a free and replenishable gift from nature is meant to be harnessed and utilized efficiently. As it is in excess round the world notably in Nigeria, could be an alternate source for green and clean energy as it is becoming the talk of the town [1]. Inconsistent power supply which is impossible to miss in many developing countries especially in Africa has been accounted for to be terribly answerable for the poor financial development of these areas [2]. One explanation behind this is that grid expansion to provincial networks is costly. Besides, the expense of stretching out the grid to these networks whenever added to the power levies gets excessively expensive and may hasten electricity destitution in such networks. With the proper design and implementation of combined systems, issues from intermittent of renewable energy sources and supply, oversizing and reliability could be taken care of. In recent years, research work on hybrid systems have been carried out and this hybrid renewable energy systems have become popular to calculate electricity demands [3]-[5] and this research have affirmed that sustainable power sources improve economic sustainability in developing nations, for example, Senegal, India, Iran, and Malaysia [6], [7]. Controlling theses system of process is seen as a vital issue [8], [9].

To consent to December 1997s Kyoto's convention on environmental change (because of carbon emanations), around 160 countries have arrived at an agreement (to go to inexhaustible/wind/PV capacity) to restrict carbon discharge which is the chief reason for an earth-wide warming [7]. In this way, the job of satisfactory clean power supply for remote arears is exceptionally fundamental. Sustainable power source innovation, for example, the photovoltaic (PV) solar power and little scale wind turbine are progressively viewed as a more secure and less expensive option for electricity supply [10]. The most encouraging business sector of sustainable power sources exist in rural areas. The inexhaustible sources are area explicit and irregular in nature. So as to have a solid system, either enormous size power plant of single based system or integrated system containing at least two renewable energy (RE) sources can be utilized. A system consisting of at least two sustainable power sources to satisfy request is known as integrated renewable energy system (IRES) [9]. Renewable energy sources are a good choice for electrification of isolated areas to meet the electricity needs of community. Depending on the availability of local RE resources, single source based, or integrated approach is used for electrification of remote areas [8].

As the world economy continues to grow, energy consumption is expected to grow too. The high cost of upgrading and strengthening existing transmission lines to meet the increasing demand for electricity, inadequate provision of new generating plants and the difficulty of acquiring way-leaves from the rural dwellers are just a few reasons most communities are without electrification. Nigeria today has 100% reliance on the grid electrification, and this has made power generated not to meet power demand. The inability of the grid extension to provide reliable electrical energy led to the need for alternate sources of reliable power. Also, global warming is now a serious case where every individual and organization is supposed to have hands on deck in other to prevent pending doom. Research shows that the level of pollution on earth is alarming and that if the pollution is not reduced or stopped, the earth is bound to become inhabitable [2]. With this important information, every human has to do everything possible to reduce their carbon footprint on the earth.

The aim of this work is the off-grid rural electrification using integrated renewable energy sources while its objectives include: calculateing load demand of the University of Nigeria, Nsukka, modelling and simulating the different combinations of RE technologies using hybrid optimization model for multiple energy resources (HOMER) software optimization technique and determining the most efficient and cost-effective configuration of the modelled system. The findings of this study will be beneficial to utility companies, institutions, health care centers, and rural dwellers. The benefits would be in terms of: pressure reduction on utility companies to supply power to rural areas, a reliable power supply for consumers, a cheaper energy source to utility users, a pollution free source of energy and for research purposes.

This study focuses on University of Nigeria, Nsukka (UNN) as a case study. Potential data are from UNN and online database sources from the National Renewable Energy Laboratory (NREL) and National Aeronautics and Space Administration (NASA). The RE sources in this work are wind, sun (solar), and biodiesel while the RE technologies includes wind turbines, solar PV, biodiesel generator, converters, and battery storage. The software used for the data analysis is HOMER which engineers and economist use to work simultaneously.

The idea of IRES was first proposed by Ramakumar. In the work of Ramakumar, Hughes, Butler, and Podriguez [11]-[15], they assessed the techno economic parts of little scale decentralized IRES for provincial territories of developing nations. The examination was completed based on the distinctive electricity requests like cooking, water system, small-scale industries and electricity using tandem and cascaded approaches. Sustainable power sources are profoundly random in nature and their seasonal occurrence tends to complement each other. A few sources are accessible in plenitude during bright season while others are accessibly plenty during the rainy season. For the supply of energy in small locality in other to achieve a cost effective and reliable system, the single technology-based system is a good option. The system could be a solar photovoltaic (SPV) system, a micro hydro power (MHP) system, a wind energy conversion system (WECS) or a biomass gasifier system. However, the use of this system on single base would not be suitable in areas of village cluster and large demand area due to high cost and low reliability. This then calls for the need to integrate these systems. The integration utilization of the different RE sources overcomes the weakness of one source with the strength of another.

Akella *et al*. [16] defined and streamlined IRES model for Jaunpur square of Uttarakhand state, India. Electric power delivery factor (EPDF) was utilized for the advancement of the system comprising of small-scale hydropower (MHP), biomass, sun based (solar) and wind electricity assets. They discovered that upgrading the IRES gives attainable solution ranging from 1.0 EPDF to 0.75 EPDF. A shortfall of EPDF under 0.75 indicates a non-achievable model.

Arabali *et al*. [17] used the genetic algorithm (GA) and a two-point estimate method to reduce the total cost of an SPV-Wind integrated system having battery storage. The battery storage capacity and excess energy (EE) were also estimated for different load shifting (LS) percentages. They were able to get the minimum total cost for the system components of the system and ensured load is reliably served. From the results, the GA converges well and the technique proposed is feasible for sizing either of the stand-alone PV system, a stand-alone wind system or an SPV-Wind energy system. In inclusion, the proposed technique from the results showed that the SPV-wind hybrid energy system is the most reliable and economic for remote areas.

Patil *et al*. [18] proposed an off-grid electrification 7 unelectrified villages in the Almora district of Uttarakhand state, India by utilizing IRES to cater for their electrical needs. During the modelling and optimization, four different scenarios were considered to ensure reliability in terms of expected energy not supplied (EENS) and energy index ratio (EIR). The customer interruption cost (CIC) was introduced to work out the total system cost, cost of energy (COE) and optimum system reliability. The fourth renewable energy technology which included 44.99% micro hydropower (MHP), 30.07% biomass, 5.19% biogas and 4.16% solar energy along with the additional resources of wind (1.27%) and energy plantation (12.33%) was discovered to be the best combination for the area having an optimal reliability of 0.95 EIR at the optimized cost of Rs 19.44 lacs with an estimated COE of Rs 3.36 per kWh.

Gupta *et al.* [19], [20] developed a hybrid system considering solar, small hydropower (SHP), biomass, biogas, fossil fuel generator and battery bank for the electrification of 9 grid isolated villages of Narendra Nagar side of Tehri Garhwal of Uttarakhand State in India. This analysis was carried out considering the demand side management (DSM) strategy with hour by hour simulations for the effective utilization of resources. Integer linear programming was used in the proposed model to determine the optimum unit cost and operation of the hybrid energy system using monthly, hourly and daily load demand with storage. The model having used the original load curves instead of the load duration curve, accurately depicting the dependency of the time of the storage operation policies over a year was shown to be sufficiently accurate. The model can be used for planning studies in determining optimum design for autonomous hybrid energy system.

In the work of [21], they presented energy management using off grid IRES for the remote areas of India. Solar photovoltaic (SPV), micro hydro power (MHP), biomass, and wind were considered as the primary energy sources and battery as storage device to electrify the cluster of 12 villages of Dewal block of Uttarakhand state of India. They suggested demand side management (DSM) using load shift strategy for energy management. The comparative analysis with DSM and without DSM was presented and finally sensitivity analysis carried out for variation in battery cost, wind turbine cost and biomass price and performance of IRES was evaluated.

This work made improvements from the reviewed works, and they include taking into account sensitivity results based on change in biodiesel price and interest rate, considering seasonal change in load, size optimization of IRESs and took it also took account of the available renewable energy resources adequate in the case study area. This work was carried out based on demand side management strategy with hour by hour simulation for effective utilization of resources. In this study, solar energy, wind energy, battery cell, and biodiesel resource-based integrated system is proposed for the electrification of the University of Nigeria, Nsukka, Enugu State, Nigeria. The essence of this work is to discover the best mix of RET from the resources readily available in a location which can meet the power demand in a sustainable and reliable manner. Estimate of the potential demand and the identification of the available resources would be used to model the generation of electricity based on different combinations of RET with the use of HOMER. Relating to cost, the optimal mix would be selected based on the COE and then compared with the performance indicators to grid extension.

## 2. RESEARCH METHOD

This is a cost estimation and design of the University of Nigeria, Nsukka, integrated power system project. The data in this work incorporates cost estimation with available wind, solar and biodiesel data. It does not include electric system drawings or construction drawings in adequate details. In essence, this is a bulk hybrid power system design, with different mix of RETs to determine cost of each configuration. Figure 1 [22] is the project site location on the map.

### 2.1. Study area

The University of Nigeria, Nsukka referred commonly as UNN, is a Federal University located in Nsukka, Enugu State in Nigeria. UNN has its location at 6°51′24″N Latitude & 7°23′45″E Longitude (552 M above sea level) [23]. Nsukka shares common border with the following towns: Eha alumona, Edem, Alor-

Uno, Opi, Orba, Obukpa, and Obimo respectively. The school campus is at a rural area with a land mass of 871 hectares (2,150 acres). Nsukka is endowed with appreciable renewable energy (RE) sources of solar, wind and biomass energy.

Figure 1. Political map of Nsukka indicating position of the University of Nigeria, Nsukka

## 2.2. Description of load area

The University of Nigeria, Nsukka has different load areas where different activities are carried out. Variation in load demand depends on the load area in the institution. The institution has different load areas which includes the residential area, the commercial area and the agricultural areas. These loads are lump into one load type which is the University community load.

### 2.2.1. Load demand

The energy used by the institution for a 12 month duration (October 2018 to September 2019). The energy consumption data is given in Table 1 [24]. It would be used for this analysis and this data is the exact power consumption data of the UNN.

Table 1. Energy consumption of the University of Nigeria, Nsukka from its UNN 11 kV feeder

| S/N | Month | Year | Unit (Kwh) | Rate (N) | Amount (N) | Vat (N) | Total amount (N) |
|---|---|---|---|---|---|---|---|
| 1. | October | 2018 | 705,479 | 45.06 | 31,788,478.2 | 1,589,423.91 | 33,377,902.11 |
| 2. | November | 2018 | 801,640 | 45.06 | 36,121,898 | 1,806,094.92 | 37,927,993.32 |
| 3. | December | 2018 | 726,910 | 45.06 | 34,376,724.6 | 1,718,836 | 36,095,560 |
| 4. | January | 2019 | 713,040 | 45.06 | 32,129,583.4 | 1,606,479.12 | 33,736,061.52 |
| 5. | February | 2019 | 928,900 | 45.06 | 41,856,234 | 2,092,811.7 | 43,949,945.7 |
| 6. | March | 2019 | 1,190,720 | 45.06 | 53,653,843.2 | 2,682,692.16 | 56,336,535.36 |
| 7. | April | 2019 | 920,090 | 45.06 | 41,459,255.4 | 2,072,962.77 | 43,532,218.17 |
| 8. | May | 2019 | 908,590 | 45.06 | 40,941,065.4 | 2,047,053.27 | 42,988,118.67 |
| 9. | June | 2019 | 821,440 | 45.06 | 37,014,086.4 | 1,850,704.32 | 38,846,790.72 |
| 10. | July | 2019 | 993,820 | 45.06 | 44,781,529.2 | 2,239,076.46 | 47,020,605.66 |
| 11. | August | 2019 | 814,630 | 45.06 | 36,707,227.8 | 1,835,361.39 | 38,542,589.19 |
| 12. | September | 2019 | 601,780 | 45.06 | 27,116,207.00 | 1,355,810.34 | 28,472,017.34 |

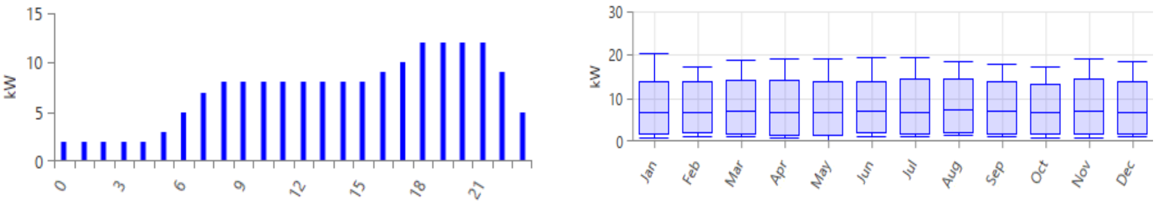
In the 12-month analysis, an average of 10,127,039 kWh (10,127.04 MWh) is used per year at an average value of 843,919.92 kWh/month (843.92 MWh). The profile of the university community load indicating the daily and seasonal load profile of the University community is given in Figure 2. Figure 2 is the load modeling using a baseline value of 168.3 and a load factor of 0.34. Table 2 shows indicates the scaling used for the simulation. Table 3 shows monthly clearness index and daily solar radiation of case study area.

Table 2. Scaling of model for simulation

| Metric | Baseline | Scaled |
|---|---|---|
| Average (kWh/day) | 165.44 | 27,843.92 |
| Average (kW) | 6.88 | 1,160.1 |
| Peak (kW) | 20.47 | 3,443.3 |
| Load | .34 | .34 |

Table 3. Monthly clearness index and daily solar radiation of case study area

| Month | Clearness index | Daily radiation (kWh/m$^2$day) |
|---|---|---|
| Jan | 0.612 | 5.681 |
| Feb | 0.582 | 5.742 |
| Mar | 0.538 | 5.571 |
| Apr | 0.502 | 5.251 |
| May | 0.484 | 4.944 |
| Jun | 0.454 | 4.543 |
| Jul | 0.412 | 4.142 |
| Aug | 0.380 | 3.911 |
| Sept | 0.407 | 4.192 |
| Oct | 0.459 | 4.574 |
| Nov | 0.545 | 5.112 |
| Dec | 0.603 | 5.463 |



(a) (b)

Figure 2. Electric load of (a) daily electric load profile and (b) seasonal electric load profile

### 2.3. Renewable resources assessment in case study area

Considered in this study simulation is the solar, wind, and biodiesel resources. The resource assessment is shown below.

#### 2.3.1. Solar energy resourse

The University of Nigeria, Nsukka is located in a region rich in terms of solar energy resources. The high resolution seasonal and annual solar resource maps and assessment was gotten from NASA. The solar radiation data from NASA website data base was gotten using geographical coordinates. Based on monthly average daily global solar radiation, the annual scaled average of solar radiation was calculated to be 4.93 kWh/m$^2$/day. The global solar radiation on horizontal surface based on clearness index and monthly averaged daily solar radiation is given in Table 3. The global solar radiation, monthly average values are for a 22 year period (July 1997-June 2019).

#### 2.3.2. Temperature resource

This is the temperature impact on the yield of the board. It is hence expected that the temperature coefficient of control is -0.51% per °C, productivity at the standard test condition is taken as 15.14% and ostensible working cell temperature of 472 °C. Table 4 gives the values of temperature in Nsukka.

Table 4. Monthly ambient temperature data of the University of Nigeria, Nsukka

| Month | Daily Temperature (°C) |
|---|---|
| Jan | 26.210 |
| Feb | 26.530 |
| Mar | 26.140 |
| Apr | 26.030 |
| May | 25.830 |
| Jun | 24.920 |
| Jul | 24.220 |
| Aug | 24.190 |
| Sept | 24.340 |
| Oct | 24.600 |
| Nov | 24.600 |
| Dec | 25.170 |

### 2.3.3. Wind energy resource

The high-resolution estimate for the annual wind power potential for Nsukka was developed using weather satellite data incorporated into a site by the NREL’s empirical validation methodology using a numerical modeling approach. Table 5 shows the data for the average wind speed data of UNN. The wind speed data is downloaded on October 12, 2019, at Anemometer height of 50 m above the surface of the earth. The values are monthly average values over a period of 20 years (July 1999-June 2019).

Table 5. Monthly average wind speed

| No | Month | Average (m/s) |
|---|---|---|
| 1. | Jan | 2.670 |
| 2. | Feb | 2.820 |
| 3. | Mar | 2.710 |
| 4. | Apr | 2.520 |
| 5. | May | 2.360 |
| 6. | Jun | 2.610 |
| 7. | Jul | 2.970 |
| 8. | Aug | 3.130 |
| 9. | Sept | 2.860 |
| 10. | Oct | 2.170 |
| 11. | Nov | 2.530 |
| 12. | Dec | 2.330 |

### 2.3.4. Biodiesel resourse

The biodiesel is a bio fuel mostly gotten from vegetable oil and at times animal fat. It is not only renewable but also toxic free unlike the conventional petroleum-based diesel. With minor engine modification, the biodiesel can be used to run diesel engines. In Nigeria, used vegetable cooking oil and Jartropha Curcas oil seed are the main feedstock for the biodiesel production thanks to extensive agriculcural research. The shelf life of the biodiesel is six months after which it would to be tested again. Nsukka which is located in the eastern part of the country has enough agricultural resource to produce adequate biodiesel which would be sold at a much cheaper price than the conventional petroleum-based diesel. The biodiesel produced from biodiesel plant is sold at the range of $0.65 per liter to $0.7 per liter.

### 2.4. Simulation

The intermittent resources in this HOMER analysis are the wind and solar radiation while the biodiesel is the backup. In storing and converting the electrical energy, the batteries and converters are used respectively. The performance and cost of each system’s components is a major factor for the cost results and the design. In order to estimate the cost of a hybrid power system, it is required to provide availability of renewable energy over a period of a year and details of each component. The HOMER software carries out the simulation of the system with the combination of the available sources and uses the detail of each component which includes operation and maintenance cost, replacement cost, capital cost, biodiesel cost and some other constraints. HOMER simulates the different combinations of these power sources and provides the optimal mix. The following section is the characteristics of each component and their source.

### 2.4.1. Photovoltaic system

In 2019, the average solar panel cost is $2.99 per Watt, but could cost more based on the PV array technology used. The PV system capital cost includes the PV array cost, structure cost, labor cost and installation cost. The capital cost for a 1 kW PV array is calculated as seen below. Based on labor wages in Nigeria, the installation cost is assumed to be $100 per kW. From (1), the capital cost is calculated.

$$Capital\ Cost\ (1kW) = PV + Installation\ Cost\ Equation$$
$$Capital\ Cost\ (1kW) = \frac{\$2900}{kW} + \frac{\$100}{kW} = \$3000 \quad (1)$$

The replacement and capital cost for a 1 kW SPV system is taken as $3000 and $3000 respectively. The operating and maintenance (O&M) costs for a PV system is on the low side (only $10 per year) as it requires little maintenance. Details of the input required by HOMER for the PV system is given in Table 6.

Table 6. PV cost specifications and installation characteristics

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| Size (kW) | 1 | Derating factor | 90% |
| Capital ($) | 3000 | Slope | 45 deg |
| Replacement ($) | 3000 | Azimuth | 0 deg |
| O&M ($/year) | 10 | Ground reflection | 20% |
| Lifetime (year) | 25 | Tracking system | No tracking |
| Size to consider | 0,1, 2…, 100 | | |

### 2.4.2. Wind turbine

The chosen wind turbine (Generic 10) gives 10 kW of DC. One-unit costs $30,000 having maintenance and replacement cost considered to be $200 per year and $30,000 respectively. The cost of the wind turbines varies based on tower height and technology used. The power output curve of wind turbine in Figure 3 indicates the amount the electrical power output will be for the turbine at different wind speeds. The complete turbine system consists of an inverter, a 24 m guyed lattice tower and tower wiring kit. The installation cost is between $5,000 and $10,000 in the selected site including the civil materials and worker wages. In other to determine the capital cost for the turbine, the (2) is utilized. Table 7 contains the detailed input for the wind turbine to HOMER.

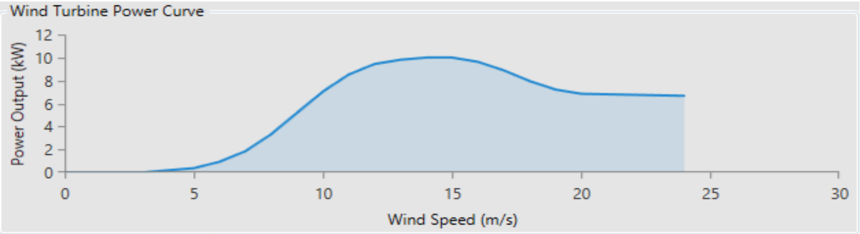


Figure 3. Power output curve of chosen wind turbine

$$Capital\ Cost\ (1Unit) = Turbine\ Cost + Installation\ Cost\ Equation$$
$$Capital\ Cost\ (1Unit) = \$20{,}000 + \$10{,}000 = \$30{,}000 \qquad (2)$$

Table 7. Wind turbine inputs specification

| Parameter | Value |
|---|---|
| Capital ($) | 30,000 |
| Replacement ($) | 30,000 |
| O & M ($/year) | 200 |
| Hub Height | 24 m |
| Power Rated | 10 kW |
| Quantity Considered | 0,1,2,3,4,5,6,7,8,9,10 |
| Life Time | 25 Years |

### 2.4.3. Biodisel generator

Generators cost varies based on brand and size. The capital cost, replacement cost and O&M cost of a 1 kW biodiesel generator are taken as $280, $280, and $0.03 per hour respectively. HOMER simulates with the different sizes of generators to determine the optimal size. A normal old diesel generator can be used as well, but it would need certain modifications. HOMER calculates the total operating cost of the generator based on the amount of time it has to be used in a year. Biodiesel prices were last reported at $0.7 per liter.

### 2.4.4. Converters and inverters

The replacement cost, capital cost, and operation and maintenance costs of the converter Leonics MTP-413F 25 (Leon25) for 1 kW systems were considered as $400, $400, and $0 per year respectively. The converter has a life time of 25 years. The efficiency of the inverter and rectifier are 90% and 85% respectively. Costs of inverters and control chargers vary based on their sizes. Different inverter sizes were also considered for the simulation.

### 2.4.5. Battery storage

When available RE is more than the load demand, the battery storage is used in the system to store the excess energy. In essence, when load demand is increases, the battery would supply its reserved excess energy to meet the need. Homer would analyze the system using both the biodiesel generator and battery storage separately to get optimal solution. Surrette 6 CS 25P Kinetic battery model type was selected. The battery has a nominal voltage of 6 volts and capacity of 820 AH with 6.91 kW of energy storage. The O&M costs, replacement cost and capital cost associated with the battery storage are $10 per year, $1,070.50 and $1,070.50 respectively. The summarized schematic of this system is given in Figure 4 which indicates the structure of the system.

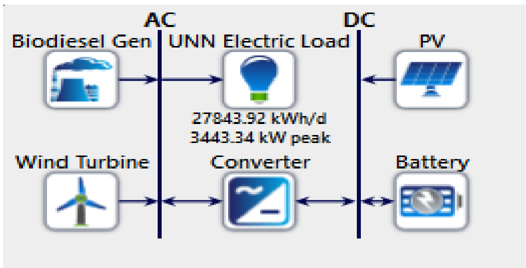


Figure 4. Schematic diagram of the project

### 2.4.6. Other constraints

Biodiesel price changes during the life cycle of the system, sensitivity variables are introduced on biodiesel price on $0.65 and $0.7 per liter to investigate the impact of the change of biodiesel price on the total cost of the system.

## 2.5. Economic modelling

Economics is very important in this simulation as total NPC and LCOE are being reduced by HOMER in getting the ideal system configuration. The chosen indicators for this work are the NPC and life-cycle cost (LCC).

### 2.5.1. Economic inputs

This work is considered to have a lifetime of 25 years with 10% annual discount rate. For the project lifetime, the system fixed capital cost is considered to be $10,000 having its O&M cost to be estimated at $500 per year. The system fixed capital costs include logistics, various civil constructions, wages, government approvals, licenses, and other miscellaneous costs. The system is also dependent on interest rate.

### 2.5.2. Analysis of HOMER

The HOMER software simulates a number of different prospective design configurations to determine the option that would satisfy the load with the system constraints at the lowest LCC. The optimization and sensitivity analysis would be done for all stated components and their technical and cost parameters. The best configuration from the result would be compared to grid extension based on LCOE.

## 2.6. Optimization process

To meet the electrical energy demand at the lowest total NPC is the aim of the HOMER simulation. HOMER would carry out sensitivity analysis simultaneously for the different input variables. HOMER concentrates on the biodiesel generator if it should carry out discharge of charge of the battery using load following or cycle charging. Although other evaluation criteria are provided in this work, the NPC and LCOE are used in ranking the optimal system. The NPC is estimated using (3).

$$NPC = \mathrm{ICC} - \sum_{y=1}^{\gamma}\left(\frac{CF_y}{(1+r)^y}\right) \tag{3}$$

Where CFy, r and ICC are cash flow during the time steps y, interest rate and initial capital cost respectively. According to HOMER, the LCOE is the ratio of the average production cost to the served energy in kWh as seen in (4).

$$LCOE = \frac{C_{ann,tot}+C_{boiler}H_{served}}{E_{served}} \tag{4}$$

The the annual cost of the system is represented as $C_{ann,tot}$ in \$/y, $C_{boiler}$ is the marginal cost of the boiler in \$/kWh, $E_{served}$ is total electrical load served in kWh/y and $H_{served}$ is total thermal load served (kWh/y). For this study, our system has no thermal load therefore $H_{served} = 0$. Since our analysis has no has no deferrable loads, the renewable fraction is based on the amount of the renewable energy that is used to serve primary load. The energy fraction supplied to the load which comes from renewable sources is the renewable fraction and its equation is given in (5).

$$F_{ren} = \frac{E_{nonren}+E_{grid,sales}+H_{nonren}}{E_{served}+H_{served}} \tag{5}$$

Where, $E_{grid,sales}$ is the energy sold to the grid (kWh/y), $E_{served}$ is the total electrical load served (kWh/y), $E_{nonren}$ is the nonrenewable electrical production (kWh/y), $H_{nonren}$ is the nonrenewable thermal production (kWh/y) and $H_{served}$ is the total thermal load served (kWh/y). In this work, $H_{nonren}$ and $E_{grid,sales} = 0$.

## 3. RESULTS AND ANALYSIS

The data used by HOMER described the RE availability, hybrid system component cost, load demand and sizes. The result consists of different combinations of each source with their initial and present cost of each of them for 8,760 hours in a year. This section presents results from the analysis. The optimization results are presented first, followed by the outcomes of the sensitivity analysis.

### 3.1. Optimization results

The optimal mix of RET system components for UNN is the combination of PV-Array, biodiesel generator, surrette 6CS25P batteries, converters, and a rectifier with a dispatch strategy of cycle charging. It is evident that from the low wind speed at UNN, the system exempted the wind turbine in its optimal mix as seen in Figure 5. This system is considered at 2.64 m/s of wind speed and \$0.7 per liter for price of biodiesel. The total NPC, capital cost and LCOE for such a hybrid system are \$55,748,730.00, \$37,668,499.25, and \$0.1900 per kWh, respectively. The monthly distribution of the produced electricity in kW by the PV and biodiesel generator (BDG) is given in Figure 5.

From Table 8 and Table 9, it is clear that the PV provides the highest amount of electricity in this case. Operation of the BDG is at full load producing 2,014,032 kWh/year with a capacity factor of 6.05%. From the operation level, the LCOE of the BDG system becomes 0.126 per kWh. For the selected system combination, operation of the biodiesel plant is for 1,134 h and consumes 564,092 L of biofuel.

Table 8. Optimization result

| Technical | | | | | | Economic | | | |
|---|---|---|---|---|---|---|---|---|---|
| PV (kW) | Wind Turbine | BDG (kW) | Battery | Converter (kW) | Dispatch Strategy | Initial Capital | Operating Cost (\$/year) | Total NPC | LCOE (\$/kWh) |
| 6,405 | 0 | 3,800 | 15,146 | 2,278 | LF | 37.7M | 626,150 | 55.7M | 0.190 |
| 6,985 | 4 | 3,800 | 16,556 | 2,318 | LF | 41.1M | 518,733 | 56.0M | 0.191 |
| 11,941 | 0 | 0 | 24,541 | 3,714 | CC | 63.6M | 242,113 | 70.6M | 0.241 |
| 13,753 | 21 | 0 | 21,773 | 3,587 | CC | 66.6M | 250,593 | 73.9M | 0.252 |
| 0 | 0 | 3,800 | 6,013 | 1,099 | CC | 8.21M | 2.62M | 83.7M | 0.285 |
| 0 | 1 | 3,800 | 6,179 | 1,086 | CC | 8.43M | 2.61M | 83.8M | 0.286 |
| 385 | 0 | 3,800 | 0 | 301 | CC | 2.61M | 3.35M | 99.3M | 0.338 |
| 0 | 0 | 3,800 | 0 | 0 | CC | 1.33M | 3.40M | 99.6M | 0.339 |
| 0 | 1 | 3,800 | 0 | 0 | CC | 1.36M | 3.40M | 99.6M | 0.340 |
| 216 | 7 | 3,800 | 0 | 126 | CC | 2.24M | 3.37M | 99.7M | 0.340 |

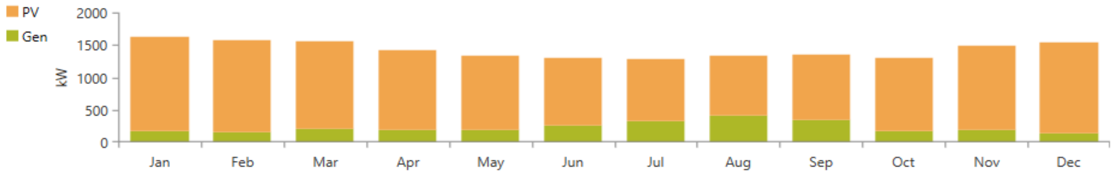


Figure 5. Monthly average electric power production

Table 9. Electricity distribution of the hybrid system

| Production | kWh/yr | % |
|---|---|---|
| Generic flat plate PV | 10,468,738 | 83.9 |
| Autosize Genset | 2,014,032 | 16.1 |
| Total | 12,482,770 | 100 |

The solar panels produce 10,468,738 kWh/year, operating for 4,485 h (or recording a capacity factor of 18.7%). The LCOE of solar electricity turns out to be $0.0697/kWh. 1,012,068 kWh/year of electricity which is 8.11% of total electricity generated goes unused due to minimal demand. This signifies that the system has the ability to meet up with the growth of demand in time to come. This increase in demand can be caused by increase in number of facilities and building complex in the school or serving the demand of other nearby villages and this cause an increase in load factor which in turn decreases the cost per kWh. The cash flow summary for the optimal system is given in Figure 6. The biodiesel generator capital cost makes up 35.31% of the total system capital cost, whereas the initial investment of 43.04% goes to the solar photovoltaic arrays.

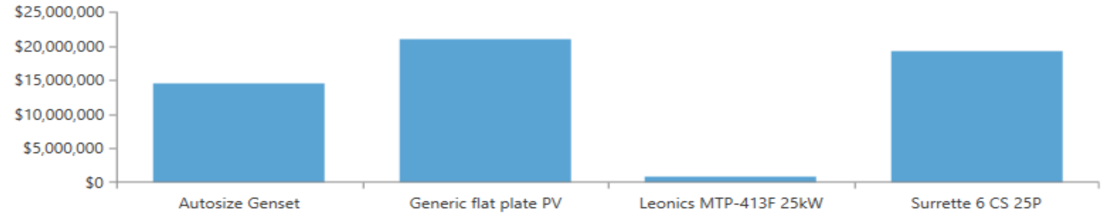


Figure 6. Cash flow summary of the optimal system

The SPV is a cheap system to maintain and operate compared to the BDG which is responsible for 26.1% of the total system annual cost. In Figure 6, the different blocks represent the total amount of money being spent on each component. From the Figure, we can deduce that most of the cost for the system is on the generic flat plate PV.

### 3.2. Sensitivity analysis

The essence of the sensitivity analysis is to detect the effect of different constraints on the LCOE of each model. In the international and local market, the biodiesel price and more outages may occur due to increase in load and or reduction in meteorological climatic resources. This reason makes it important to carry out the sensitivity analysis. In this analysis, the effect of a change in the biodiesel price and interest rate on the net present cost of the optimal system configuration is determined. The biodiesel price is varied from $0.65 to $0.7 per liter for this study and it was observed that the lower the diesel price, the lower the NPC. Table 10 is the change caused by the varying of the interest rate from 0% to 10% of the NPC. For equity participation, the 0% was added for the project funding. In essence, an investor borrows money from financial institutions to pay back the loan without interest but sharing the profit with the financial institution. It is evident from the different configurations considered that the NPC decreased as the interest rate decreased. Table 10 also shows hows the change in interest affects the RF and LCOE for the different configuration as interest is directly proportional to the LCOE.

Table 10. Sensitivity result of the system

| Technical | | | | | | Economic | | | |
|---|---|---|---|---|---|---|---|---|---|
| PV (kW) | Wind Turbine | BDG (kW) | Battery | Converter (kW) | Dispatch Strategy | Initial Capital | Operating Cost ($/year) | Total NPC | LCOE ($/kWh) |
| 6,405 | 0 | 3,800 | 15,146 | 2,278 | LF | 37.7M | 626,150 | 55.7M | 0.190 |
| 9,205 | 0 | 3,800 | 18,445 | 2,318 | LF | 50.1M | 140,157 | 58.1M | 0.0998 |
| 6,717 | 0 | 3,800 | 15,139 | 3,714 | LF | 38.6M | 589,881 | 56.9M | 0.180 |
| 9,231 | 0 | 3,800 | 18,162 | 3,587 | LF | 49.9M | 113,864 | 57.0M | 0.0898 |
| 6,405 | 0 | 3,800 | 15,146 | 1,099 | LF | 37.7M | 626,150 | 55.7M | 0.190 |
| 9,205 | 0 | 3,800 | 18,445 | 1,086 | LF | 50.1M | 140,157 | 58.1M | 0.0998 |
| 6,717 | 0 | 3,800 | 15,139 | 301 | LF | 38.6M | 589,881 | 56.9M | 0.180 |
| 9,231 | 0 | 3,800 | 18,162 | 0 | LF | 49.9M | 113,864 | 57.0M | 0.0898 |

For the fourth configuration an optimum LCOE gotten is based on 11.8% inflation and 5% discount rate. The RF was constant at 97.9%. It is important to note that the optimal configuration was not altered as the interest rate increases. This is because HOMER orders for a solution according to NPC which is cost-optimal and in turn sensitive to the interest rate. The RF can be affected as the reorder of technologies contributing to RS could decrease or increase.

## 4. CONCLUSION

This paper evaluates the technically feasible and economically viable hybrid system based on the possibility of 100% RES. The best combination of HRES has been determined after evaluating different performance criteria such as excess electricity, LCOE and NPC. The UNN has been used as a case study. In considering various scenarios of interest rate and different biodiesel price, the optimal generation mix of the power source was determined. The hybrid system is made up of PV/Biodiesel generator and battery storage of various output power rating. The LCOE from the system is $0.19 per kWh. The biodiesel plant and solar plant contributes 16.1% and 83.9% respectively to electricity generation as the wind turbine was not part of the optimum combination. If the biodiesel generator is not available, the electricity demand can be met with a hybrid system comprising of solar PV, wind turbine and battery storage but the cost of electricity will increase thereby making the system less attractive. The sensitivity analysis shows that interest rate is directly proportional to the LCOE and inversely proportional to the NPC. Additionally, as the biodiesel price increase, the NPC also increases. The optimal result from the sensitivity analysis gave an LCOE of $0.0898 per kWh which is much cheaper when compared to school's grid electrification rate $0.125 (N45.06k). With this hybrid system UNN would spend less on electricity on the long run. The electricity generated is a reliable one i.e., there would be power supply for 24 hours in a day as there would be no shortage. An added advantage of this system is that the carbon foot print of UNN would be reduced due to the use of a clean and pollution free source of energy. This study has been able to prove that the integration of renewable energy systems is more economical when compared to grid extension.

## REFERENCES

[1] M. Osama, I. Mohamed, A. Mahmoud, and M. Fahmy, "Techno-economic analysis of hybrid renewable energy power network for new community in Egypt, case study New El-Farafra Oasis," *International Journal of Engineering Research and Advanced Technology (IJERAT)*, vol. 4, no. 5, May, 2018.

[2] O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, and C. Stechow, *Renewable energy sources and climate change mitigation*, Cambridge: Cambridge University Press, 10.1017, 2011.

[3] I. Mohamed and H. S. Ramadan, "Power quality enhancement of grid connected fuel cell using evolutionary computing techniques," *International Journal of Hydrogen Energy*, vol. 43, no. 25, pp. 11568-11582, 2018.

[4] M. Qolipour, A. Mostafaeipour, O. Mohseni, "Techno-economic feasibility of a photovoltaic-wind power plant construction for electric and hydrogen production: a case study", *Renewable and sustainable energy reviews*, vol. 78, pp. 113-123, Oct., 2017.

[5] S. Nandi and H. Ghosh, "Prospect of wind–PV–battery hybrid power system as an alternative to grid extension in Bangladesh," *Energy*, vol. 35, pp. 3040–3047, 2010.

[6] A. Gritsevskyi, "Renewable vs. non-renewable energy sources, forms and technologies prepared," *IAEA*, [Online]. Available: https://unstats.un.org/oslogroup /meetings/og-04/docs/oslo-group-meeting-04-comments-issue-3.2-iaea.pdf. [Accessed: Aug 10 2019].

[7] S. Shaahid and I. El-Amin, "Techno-economic evaluation of off-grid hybrid photovoltaic– diesel–battery power systems for rural electrification in Saudi Arabia-A way forward for sustainable development," *Renewable and Sustainable Energy. Reviews*, vol. 13, no. 3, pp. 625-633, 2009.

[8] M. I. Mossad, "Model reference adaptive control of STATCOM for grid integration of wind energy systems," *IET Electric Power Applications*, vol. 12, no. 5, pp. 605-613, 5 2018.

[9] M. I. Mossad, N. I. Elkalashy, and M. G. Ashmawy, "Integrating adaptive control of renewable distributed switched reluctance generation and feeder protection coordination," *Electric Power System Research*, vol. 154, pp. 452-462, 2018.

[10] Y. Lu, N. Nakicenovic, M. Visbeck, and A. Stevance, "Policy: five priorities for the UN sustainable development goals," *Nature*, vol. 520, pp. 432-433. 2015.

[11] R. Ramakumar, W. L. Hughes, "Renewable energy sources and rural development in developing countries," *IEEE Transactions on Education*, vol. 24, no. 3, pp. 242-251, 1981.

[12] R. Ramakumar, "Renewable energy sources and developing countries," *IEEE Trans Pow App Sys*, vol. PAS-102, no. 2, Feb. 1983.

[13] R. Ramakumar, N. G. Butler, A. P. Podriguez, "Economic aspects of advanced energy technologies," *Proceedings of IEEE*, vol. 81, pp. 318-321, 1993.

[14] R. Ramakumar, "Energizing rural areas of developing countries using IRES," In *IECEC 96. Proceedings of the 31st Intersociety Energy Conversion Engineering Conference*, pp. 1536-1541, 1996.

[15] R. Ramakumar, "Role of renewable energy in the development and electrification of remote and rural areas," *IEEE Pow Engg Soc Gen Meeting*, vol. 2, pp. 2103–2105, 2004.
[16] A. K. Akella, M. P. Sharma, and R. P. Saini, "Optimum utilization of renewable energy sources in a remote area," *Renew Sustain Energy Rev*, vol. 11, pp. 894-908, 2017.
[17] A. Arabali, M. Ghofrani, M. Amoli, M. Fadali, and Y. Baghzouz, "Genetic algorithm-based optimization approach for energy management," *IEEE Trans. Power Deliv.*, vol. 28, pp. 162-170, 2016.
[18] A. B. Patil-Kanase, R. P. Saini, and M. P. Sharma, "Sizing of integrated renewable energy system based on load profile and reliability index for the state of Uttarakhand in India," *Renew. Energy*, vol. 36, pp. 2809-2821, 2015.
[19] A. Gupta, R. P. Saini, and M. P. Sharma, "Modeling of hybrid energy system – Part I: problem formulation and model development," *Renewable Energy*, vol. 36, no. 2, Feb., pp. 459-465, 2011.
[20] A. Gupta, R. P. Saini, and M. P. Sharma, "Modeling of hybrid energy system – Part 3: case study with simulation result," Renewable and Sustainable Energy Reviews, *Renewable Energy*, vol. 36, no. 2, pp. 474-481, 2011.
[21] A. M. Patel and S. K. Singal, "Off grid rural electrification using integrated renewable energy system," *2016 IEEE 7th Power India International Conference (PIICON)*, Bikaner, pp. 1-5, 2016.
[22] Google, "Nsukka," [Online]. Available: https://www.google.com/maps/, Accessed Jul. 6, 2019.
[23] NASA, "Surface meteorology and solar energy website," [Online]. Available: https://asdc.larc.nasa.gov/, Accessed Jul 10, 2019.
[24] Electrical Billing Section, *Works Services Department*, University of Nigeria, Nsukka Enugu State, 2019.

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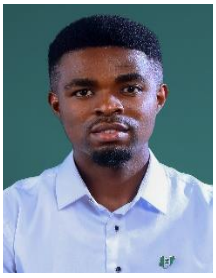

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