

TECHNO-ECONOMIC DESIGN AND INTEGRATION OF SUSTAINABLE HYBRID PV/WIND/DIESEL TURBINE GENERATION INTO THE NIGERIAN POWER SYSTEM

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Abstract: Economic development in any country depends largely on efficient, reliable and affordable electricity supply. Nigeria is one of the countries in the West African sub-region with an estimated population size of about 200 million people. Out of this only 45% have access to electricity. The current total grid generation capacity is estimated at 7MW which supplies commercial, industrial, social and institutional centers as well as residential areas. This is gross inadequate for meaningful development. Based on this, it's the aim of this research to diversify and integrate the power sector, thereby tapping into the various energy sources including renewable. In this research titled "Techno economic design and integration of Sustainable Hybrid PV/Wind/Diesel Turbine generation into the Nigerian power system", the idea is to integrate fossil fuel energy sources with renewable (photovoltaic) to generate a higher energy output at a lower cost while minimizing environmental pact. A Techno-economic environmental optimization framework will be developed and implemented in HOMER, a simulation software used for modeling renewable energy and tested on the Nigerian power system. The outcome of the research reveals that, not only does the hybrid system configuration perform better than base case simulation when compared with the NPC for all six simulations; it also displayed better performance in the categories such as electrical, fuel consumption and CO2 reduction.

Keywords: Renewable Energy Systems; Hybrid Energy Designs, Optimization and Integration; Battery Storage; Electricity Generation.

1. INTRODUCTION

The supply of clean, eco-friendly, efficient, reliable and affordable electric power is a panacea to foster development in any country. For Nigeria to keep pace with other technologically advanced countries of the world which have shown a significant growth in economic development, the existing gap between the electric power demand and supply of the country must be bridged. Till now, Nigeria is still entrenched in constricted opportunity for development due to frequent outages or total blackout resulting from shortage in generation, as well as in adequate transmission and distribution infrastructure. Clean, economic and secure energy production gains importance with the increasing of the world's power demand. So, a new type of energy sources has gained popularity. The sun and the wind energy are more common alternative energy sources.

Previously, they were used to supply local loads in remote areas outside the national grid. Later, they have become some of main sources [1] [2]. Renewable energy sources are operated in standalone mode or grid tie mode. It is often hard to obtain an efficient operation in stand-alone mode and usually high capacity battery groups are required. Since the electric energy generated from the wind or the solar panels are being wheeled to the grid, the way of the transforming (DC) energy to (AC) is very important. This process has it been achieved by the use of a grid tie inverter; inverter supplies the local loads and if the generated energy higher than the demand, then the excess energy is being exported to the grid, so battery groups are not needed.

On the other hand, the control of the grid tied inverter involves a more complex process than the stand alone one. [2] The electric power generation system, which consists of renewable energy sources connected to grid, has the ability to provide 24-hour electricity to the load. This system offers a better output performance such as reliability, efficiency, flexibility of planning and environmental benefits when compared to the stand-alone system. It has been proven that each kilowatt-hour (kWh) generated from renewable resources saves the environment from the burning of fossil fuels. The coal fired and the natural gas fired power plants produce 1.05 kg and 0.75 kg carbon dioxide, respectively, to generate 1KWh electricity [3].

The alarming rate of global warming and the depletion of the Ozone layer have grown worrisome over the years.

This challenge has been on the increase. Most of the energy generated/supplied is achieved from fossil fuels. However, major draw backs are associated with fossil fuels sources including the fluctuated prices, environmental pollution, and finite resources.

To overcome these challenges, renewable energy resources are considered a viable option for integration with conventional fossil fuel power plants to enhance the energy growth and improve the energy reliability as well as environmental health.

In this paper titled "Design with Techno-Economic and Carbon Credit Optimization of Grid Hybrid Photovoltaic/Wind/Diesel Power System into the Nigerian Power System Using HOMER" Model is to achieve the following:

1. Integrate fossil fuel with renewable energies and produce a more efficient hybrid system that can overcome the limitations of the RES's including the intermittency and the energy quantity. Such hybrid schemes can deliver more reliable sustainable and environmental friendly system. Among the RES's technologies, solar energy technologies demonstrate a significant advancement and maturity for power generation. By this integration with non-renewable sources (Diesel Generator), a more reliable and eco-friendly power is generated.

2. To possibly predict accurately the voltage output from grid connected photovoltaic arrays by including the effect of temperature and solar radiation. It will be shown how possible it is to adapt the size of models and the different PV hybrid system configurations which are applicable to a grid connection and modify it in such a way that important information about techno-economic performance of these systems can be obtained. Upon achieving this, a side-by-side comparison of different grid connected PV sizes will be performed. The form of this model will be justified by looking at different measured values over the collection period; such as; power output versus radiation, voltage versus radiation and output versus radiation, voltage versus radiation and output power versus temperature. These plots should give an appropriate reason for the sizes and percentage of penetration factor for all parameters connecting with grid.

3. The software Hybrid Optimization Model for Electric Renewable program will be used to determine the effect of temperature coefficient and non-linear radiation term, the maximum power output from each PV hybrid system sizes and configuration can be predicted with accuracy. This can be done,

not only for a single unrealistic value of solar radiation, but under general operating conditions. Being able to accurately predict the power output is very important for increased growth in the deployment of photovoltaic hybrid systems.

4. To determine the barriers/constraints: Annual electricity demand, Reliability, Net Present cost, Environmental factors, and Employment. Some Hybrid renewable system configurations and being used are as follows: Wind/ Diesel/ Battery/ converter, PV/ Diesel/ Battery/ converter, Diesel/ Battery/ converter, PV/ Standalone, Wind/ Diesel, PV/ Wind/ Battery/ converter, Diesel/ Diesel/ converter, PV/ Battery/ converter, PV/ Wind/

5. To simulate the System configuration optimization using HOMER to meet load demand and evaluation carried out on the basis of power reliability and system life cycle cost.

In view of the above, this research is structured into eight different sections. The first section gives an introduction to the research, including the problem statement, aim/objectives. Section II contains the review of related literature. The methodology of the renewable hybrid system description, specification of components, and designs is presented in section 3. And in Section IV, is the system description and presentation. In section V, Data presentation, results analysis and discussion on the input parameters to be used in order to carry out the PV/Wind/Diesel hybrid simulation software HOMER. The Operating strategies of the hybrid Solar PV/Gas/battery system and aspect concerning its economic analysis were further presented. Finally, Section VI presents the conclusion.

II. REVIEW OF RELATED LITERATURE

In Nigeria, government efforts on rural electrification have stalled with inadequate transmission lines, resulting to a very low voltage profile and uneven distribution in electricity among rural areas. This poor supply of electricity has hindered future development (both socio and economic) of the rural area. Also, lack of power supply in rural areas has thus heightened the poverty level of the country. The technology for sustainable development is one of the proven tools in reducing energy poverty if carried out with an appropriate policy [4]. The worldwide use of RETs to meet energy demands, has been increasing over the years [5].

These technologies have demonstrated their capability to contribute substantially to global climate protection by reducing the greenhouse gas emission, as well as offering low operation and maintenance cost, while meeting the rapid energy demand growth [6]. Among the various renewable energy sources, solar and wind are highly abundant and accessible irrespective of the location (remote or otherwise). Remote location in this regards may not necessarily be referred to a location far away from the national grid only, but it also includes any site or settlement where it is not economical or feasible to extend grid network due to bad terrain and poor topography which is mostly characterize isolated desert places in Nigeria and other developing countries. Hence, small off-grid standalone renewable energy systems represent an important option for narrowing the electricity gap in rural parts of developing world, where progress in grid extension remains slower than population growth [7].

Rural population refers to people living in rural areas as defined by national statistical offices. The low electricity supply situation in the country has undoubtedly contributed to the poor socio-economic status of the rural communities in Nigeria. According to the international fund for agricultural development [8], up to 80% of rural communities in Nigeria live below the poverty line.

Many entrepreneurs and owners of small scale businesses in the rural areas cannot afford the cost of acquiring or fueling power generating sets.

This situation was further worsened by removal of subsidy on fuel by the federal government of Nigeria in 2012. As a result, many have abandoned their businesses out of frustration. In many cases, these experiences have led to rural-urban migration shift in such communities, whereby the young and productive youths move to the cities leaving the old and feeble ones behind. This has also led to the increase in the number of the poor in the urban centers; thus culminating in a situation where the rural communities are made socially backward, leaving their economic potentials untapped [9]. Electricity is thus seen as one of the vital tools for productivity as its importance can never be over emphasized. An area having no electricity access usually lack essential infrastructures such as school, medical center, communication, portable water supply, etc. The Human development index values in electrified communities, is found to be higher than the non-electrified communities [10]. National grid extension through the thick jungles and difficult topography in most villages may be difficult and uneconomical due to the associated high cost as well as transmission loss considering the distance from available grid to the load centers [11].

The use of diesel generator may be reliable for electricity generation for rural villages when properly operated and maintained; however, it may pose lots of disadvantages including noise and environmental pollution due to emission of CO₂ and other harmful gases. It may also be difficult to maintain due to unpredictable hike in diesel price including additional cost of transportation to remote locations. Considering the fact that improving rural access to electricity through extension of the national grid to rural communities does not look promising at present, it is thus imperative that a system autonomous, off-grid power generation be established for rural communities in Nigeria. Such a solution would be viable if it is based on renewable energy (RE) resources since RE resources are always available and environmentally friendly. In addition, rural dwellers have a low demand of electricity in which RE-based power sources would be able to meet their electricity needs easily. Despite the vast abundance of renewable resources in Nigeria, only the hydroelectric source is being utilized most for power generation, and that is even at an exploitation rate which is below the full potential [12].

In summary, a review of related literature shows that sufficient energy supply is indispensable for sustainable economic development of any nation. Various simulations software has been deployed by researchers in the past in the area of renewable energy as well as integration. But in recent times, HOMER has been proven to be the most widely used and efficient optimization tool for modeling.

It is a sophisticated tool or computer model that facilitates the design of stand-alone electric power systems and performs simulations to satisfy the given load demand using alternative technology options and resources availability which is its major advantage over other software's. HOMER simulates a HPS, based on the hourly time stepped load data profile and the average monthly weather data of the specific location over a period of one year. With this information and the choice of component sizing and pricing, HOMER is able to simulate the most economically and technically feasible solution for any specific climate zone.

III. METHODOLOGY USED FOR ANALYSIS

HOMER software is one of the most widely used optimization tool for modeling the HPS. It is a sophisticated tool or computer model that facilitates design of stand-alone electric power systems and performs simulations to satisfy the given load demand using alternative technology options and resources availability. HOMER simulates a HPS, based on the hourly time stepped load data profile and the average monthly weather data of

the specific location over a period of one year. With this information, the choice of component sizing and pricing, HOMER is able to simulate the most economically and technically feasible solution for any specific climatic zone.

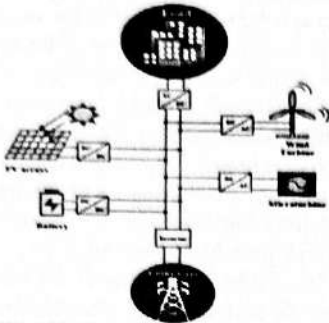


Figure 1.0: Hybrid PV/Wind/Diesel System with the Battery Storage

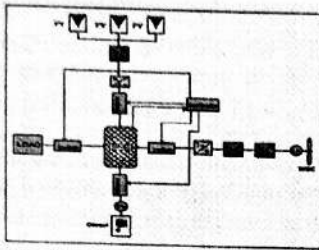


Figure 2.0: The Modified Distributed Bus AC Architecture

TABLE 1:
SHOWS THE SELECTED TOWNS IN THIS STUDY WITH LOCATIONS, STATES IN SOUTH-SOUTH GEO-POLITICAL ZONE, LATITUDE/LONGITUDE AND CLIMATE TYPE

Selected Location	States in South-South Geo-Political Zone	Latitude(N) /Longitude (E)	Climate Type
Iwofe	Rivers State	4°48'51.9"N 6°56'56.7"E	Tropical Wet
Wiberforce island	Bayelsa State	4°58'22.8"N 6°06'14.0"E	Tropical monsoon
Ikpa	Akwa Ibom State	5°02'16.2"N 7°55'26.3"E	Tropical monsoon
Okada	Edo State	6°48'54.1"N 3°50'36.4"E	Tropical
Edibefidibe	Cross River State	4°55'42.0"N 8°19'45.8"E	Tropical monsoon
Abraka	Delta State	5°47'28.2"N 6°05'50.5"E	Tropical

A. Basic Mathematical Description of System Components

The detailed mathematical model of the components of the proposed hybrid system (PV panels, wind turbines, diesel generators, batteries) and the control strategy is being expressed below with a brief description as follows;

1) PV Model:

Using the solar radiation available, the hourly energy output of the PV generator (E_{PVG}) can be calculated according to the following equation.

$$E_{PVG} = G(t) \times A \times P \times n_{PVG} \dots \dots \dots (1)$$

An assumption was made that the temperature effects (on PV cells) will be ignored.

Where;

$$G(t) = \text{hourly irradiance in } kWh/m^2$$

- A = surface area in m²
- P = PV penetration level factor
- n_{PVG} = efficiency of PV generator

2) Wind Turbine Model:

Wind energy is transformed into mechanical power through wind turbine and then converted into electrical power. The mechanical power over an area A is given in Dufo-Lopez and Bernal Augustine as:

$$P_m = \frac{1}{2} \times \rho \times A \times V^3 \dots \dots \dots (2)$$

Where;

- ρ = air density (1.225kg/m³)
- V = wind speed (m/s).

The electrical power of the wind energy conversion system is given by:

$$P_w = \frac{1}{2} \times \rho \times C_p \times A \times V^3 \times 10^{-3} \dots \dots \dots (3)$$

Where;

- C_p = maximum power extraction efficiency of the wind generator And other electrical components connected to the generator.

3) Diesel Generator Consumption Model:

The renewable energy systems have intermittent output characteristics and are integrated with conventional power sources to deliver a steady power output. In various HPSs, diesel generator (DG) acts as steady source of power. The DG systems are designed to supply the load and also charge the battery energy storage system, if the renewable energy source together with battery is unable to supply the load. Power energy balance is required for optimum system operation as the consumption of fuel is proportional to the power being supplied by the DG. The fuel consumption of the diesel generator (F_G in l/h), is modeled as dependent on the DG output power as;

$$F_G = B_G \times P_{G-rated} + A_G \times P_{G-out} \dots \dots \dots (4)$$

Where;

- $P_{G-rated}$ = nominal power of the diesel generator,
- P_{G-out} = output power,

While A_G and B_G = coefficients of fuel consumption curve as defined by the user (l/kWh).

4) Battery Energy Storage System:

Battery is a storage device essential for storing electrical energy for maximum utilization of the intermittent renewable resources. The lead-acid battery which is often used in HPS is a complex nonlinear device controlling operational states of the system. Modeling of lead-acid batteries for real time analysis of HPS must account for the dependence of battery parameters on; (i) state of charge, (ii) battery storage capacity, (iii) rate of charge/discharge, (iv) ambient temperature, (v) life and other internal phenomenon, such as gassing, double layer effect, self-discharge, heating loss and diffusion. The battery storage capacity is given as follows;

$$C_{wh} = (E_L \times AD) / (\mu_{inv} \times \mu_{batt} \times DOD) \dots \dots \dots (5)$$

Where;

- E_L = average daily load energy (kWh/day),
- AD = daily autonomy of the battery;
- DOD = battery depth of discharge,

While

$$\mu_{inv} \text{ and } \mu_{batt} = \text{inverter and battery efficiency respectively.}$$

Figure 3 below shows the flowchart of economic analysis of HPSs. At the beginning of techno-economic communities were visited and loads as well as meteorological data in different geographical locations were analyzed. The studies revealed the two possible renewable energy sources that could be used to address the energy challenges of the rural locations which include solar and wind energy systems. Thereafter, the modeling of the proposed hybrid systems, with the gathering of information about primary load, solar and wind potential, capacity of power generated as well as typical market prices of the different components constituting the hybrid system. In a one-source renewable system, the system tends to be oversized to accommodate the load demand with attendant result in high capital cost, while this is not the case in hybrid system because the various connected energy sources, complement one another by utilizing their individual generators load factor. The sizing of components that need to be considered in order to meet the load demand in this particular study are; PV array, wind turbine, diesel generator, converter, and number of battery.

The following system configurations were analyzed in this study including; stand-alone diesel system, hybrid PV-diesel and without battery, hybrid wind-diesel system with and without battery, PV-wind-diesel system with and without battery. The economic feasibility of each configuration is based on the net present cost (NPC); two other parameters such as levelized cost of energy (COE) and renewable fraction are also considered. CO₂ emission (tons/yr) and consumption of diesel (l/yr) are two essential factors considered for the analysis of environmental friendly solution.

All the input parameters are fed into the HOMER software in order to determine the optimization results for different systems configurations. The system configuration that gives minimum COE is optimized in order to minimize its excess energy. The amount of power generated by the HPSs components, is compared to the annual load demands to ensure that it is able to meet the load demands. In addition, the stand-alone diesel system, PV-wind-diesel system with battery, and PV-diesel system with battery, were analyzed bearing in mind the variations in diesel prices.

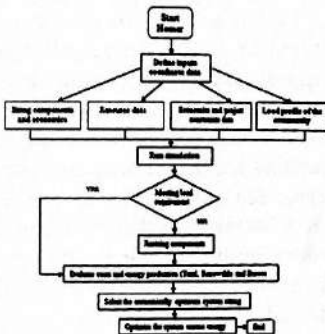


Figure 3: Flowchart of Economic Analysis of Hybrid Power System.

C. Evaluation Performance Criteria

HOMER compares the economics of a wide range of system configurations comprising variable numbers of renewable and non-renewable energy sources [13]. For equality, such comparisons must account for both capital and operating costs of each energy sources. In this study, three parameters including NPC, COE, and RE were used to evaluate the performance of the hybrid system.

1) Net present cost (NPC):

In HOMER, the system life-cycle cost is represented by total net present cost (NPC). The NPC comprises of initial capital cost, replacement cost, annual operating and maintenance cost as well as fuel costs. NPC is expressed in the equation (6)

$$C_{NPC} = TAC / CRF (i, N) \dots\dots\dots (6)$$

Where;

TAC = total annualized cost (\$/year);
 CRF, the capital recovery factor is a function of annual real interest rate (i), and the project lifetime (N) in years, CRF is given in equation (7).

$$CRF (i, N) = i(1+i)^N / (1+i)^N - 1 \dots\dots\dots (7)$$

2) Levelized cost of energy (COE):

Levelized cost of energy is defined as the average cost per kilowatt-hour of useful electrical energy produced by the system. HOMER uses equation (8) to calculate the levelized cost of energy.

$$COE = TAC / E_{\text{annual output}} \dots\dots\dots (8)$$

Where,

E_a is the total annual load served by the system in kWh.

3) Renewable fraction (RF):

Renewable fraction (RF) is the total amount of power generated by the renewable energy sources compared to total power generation from the entire hybrid system. RF is usually designed to be as high as possible, but bearing in mind its effect on NPC, this is because the load is expected to make the maximum use of the renewable energy. The renewable fraction is obtained from;

$$RF(\%) = (1 - (\sum P_{\text{diesel}} / \sum P_{\text{ren}})) \times 100 \dots\dots\dots (9)$$

Where;

P_{ren} = power output of the connected renewable energy sources (PV and wind in this case).

IV. SYSTEM DESCRIPTION AND IMPLEMENTATION

This section presents all the tools and systems used for the study. These include: the load profile, the simulation and optimization software, and a supervisory controller for the energy management.

A. Load Profile

In this study, Domestic and Infrastructural loads have been considered for energy provision in each of the selected community. A total of 50 households, 1 primary health center, 1 public primary school, Salon shop, Provision shop, Stationary Shop, 1 community hall and a few miscellaneous loads were assumed in each location. The demands were estimated monthly from January to December. Figure 4 shows daily load profile for each month. Measured hourly load profiles are not available for the selected sites; load data were thus synthesized by specifying typical daily load profiles. Characteristics of the load categories are:

1) Domestic load:

For each household, the load is based on four energy efficient compact fluorescent lamps (20 W each), 2 ceiling fans (30 W each), one television (80W) and one radio (10W). The load demand is approximately 108kWh/day.

2). Social Infrastructure:

This includes the demand for the primary health center, public primary school, community hall and shops. The load demand is approximately 15kWh/day.

B. Solar Radiation

The power output of the PV array depends largely on the direct and diffuse solar radiation over a given area. The radiation reaching the earth's surface depends on the cloudiness or clearness of the sky, which in turn depends on the season of the year. Solar energy is one of the readily available sources of clean

energy in Nigeria. Nigeria has average solar irradiation of about 5.75 kWh/m²/day with average sunshine of 4-7.5 h daily. Table 3 shows the solar irradiation for each selected location as obtained from the Solar Electricity handbook global satellite database (www.solarelectricityhandbook.com/solar-irradiance.html) [14]. Using solar panel direction: East South East (67.5°). The solar radiation data for all six sites were obtained according to their respective latitude and longitude, as earlier presented in Table 1 and measured by precision pyrometer.

For all the villages considered, there are less solar intensity and solar irradiation during the wet periods as compared to dry season. Southern region of the country shows the low irradiation potential requirement for substantive power generation. Generally, all the location considered are found to be heavily over cast between July and August (peak of rainy season), leading to a remarkable fall in global solar potential due to the high cloud cover.

The initial costs of the PV array are the PV panel costs according to the size of the PV panel type, the percentage of capital costs added for installation and BOS (Balance of System) parts, and added fixed costs accounting for installation and BOS parts, respectively. Operation and maintenance of PV arrays can be described with monthly fixed costs and yearly costs as a percentage of capital costs. These payments can cover system inspection by a maintenance person. Replacement events of PV arrays are assumed to occur after every 20 years, so for a project life of 20 years or less, there will be no PV replacement cost.

C. Windspeed

Electrical energy can be generated from wind energy when wind blow through a wind turbine. The kinetic energy of the wind at rated wind speed is converted into mechanical power by turning the turbine blade, thus producing electricity through the shaft connected to the alternator. The monthly average wind speed data for an average of ten (10) years were obtained from Time and Date Weather global database (www.timeanddate.com/weather/nigeria) [15] on the latitude and longitude of the different selected villages using anemometer at 10m above sea level. The annual average wind speed for each village is presented in Table 4. The wind speed from the selected site ranges from 2.9 to 6.9 m/s. The changes in the wind patterns occur as a result of earth's topography, bodies of water and vegetation cover. Observation of the wind probability and average monthly speed for a year, show that the peak wind speed occurs at 15.00hrs. The average wind speed of Iwofe village is shown in figure 5.

The wind turbine costing variables (initial cost, operation cost, and replacement cost) are similarly derived as for the PV array. Wind turbine operating costs comprises of the maintenance and replacement costs. Maintenance costs for wind turbines can vary depending on the application, type of maintenance and wind turbine sizes. The wind turbine life is often assumed to be more than 20 years; therefore, in many life cycle costing no wind turbine replacement will take place.

D. Diesel

The current diesel price in Nigeria \$0.56/liter (currency conversion rate is 356 naira to 1 dollar). This price varies according to the global market. In this research, diesel price is assumed to be constant in order to investigate its effect on the entire system cost and environment.

The initial costs of the diesel generator are the diesel generator cost according to the size of the diesel generator type, the percentage of capital costs added for installation and BOS parts for diesel generator type and the corresponding added fixed costs. The diesel generator operating costs comprise fuel costs, and maintenance, overhaul and replacement costs.

The fuel costs occur whenever the fuel storage tanks are refilled. Overhaul is assumed half way through the diesel lifetime. Replacement occurs after a certain number of diesel generators run time hours. The effective lifetime of a diesel generator is defined by the time until a mechanical overhaul becomes uneconomic (i.e. when overhaul costs exceed 60% of the replacement costs). Factors that affect lifetime include the quality and regularity of maintenance, the average capacity factor and the number of start-ups. An air-cooled machine is likely to have a shorter life than a water-cooled unit that can keep the operating temperature down.

E. Components Data

The proposed hybrid systems consist of PV panels, wind turbines, diesel turbine generators and other system components such as batteries, converters etc. The PV panel, wind turbine and diesel turbine generator combined to harness the overall system output as well as to compensate for the unpredictable variation in RE sources from one zone to another. Maintenance and replacement costs of the hybrid system can be reduced when renewable resources are adequately explored. The initial capital cost of a hybrid system is usually high; hence, long-lasting, reliable, and cost-effective systems are needed to meet the entire project life.

Assumptions regarding components pricing and sizing as adopted in the proposed hybrid system, are expressed below; the capital cost and replacement cost of 1W of PV array were taken as \$3.0 and \$2.0 respectively (Price from eBay store). The lifetime of PV arrays was taken as 20 years. The de-rating factor that accounts for losses due to temperature effects and dirt's on the PV modules surface was assumed as 90% and the ground reflection of the modules were taken as 20%. Different sizes of PV arrays were considered to get the optimal size for each village.

F. Dispatch strategy and Constraints

A dispatch strategy is a set of rules that controls the function of several connected generator(s) and the energy storage device. Two types of dispatch strategies are available in HOMER software, namely; cycle charging (CC) and load following (LF). Under the LF strategy, diesel generator is automatically operated to serve the load alone without charging the battery storage system; under the CC strategy, the generator operates at its maximum rated capacity to serve the load and charges the battery.

The type of dispatch strategy which will be optimal for the proposed system depends on various characteristics such as the generator sizes, the battery bank, the fuel price, the diesel generator's operating and maintenance cost and the renewable energy. In the proposed system, both strategies were considered using HOMER. Constraints are pre-conditions which systems must fulfill; otherwise HOMER neglects those systems that do not content the defined constraints. In the proposed system, the maximum renewable fraction is considered as a range from 0 to 100%, and the excess energy depends on the location resources, while 2% values was taken as the maximum annual capacity shortage.

PV sizing in HOMER is user dependent; HOMER allows user to specify any amount of PV size (in kW) to allow for worst case scenario (i.e. period of low solar irradiance). The sizing of the PV may also depend on the power requirement of the site as well as the space availability to install the panels. But in this study, the entire PV modules in the hybrid system were sized for each site to meet the worst cases during the year. Although the amount of excess energy produced becomes prominent during the months of high solar radiation due to larger size of the PV choice, because the greater the PV capacity, the greater the amount of electricity generated by the PV modules during daytime.

The software used in this research (HOMER) performs an hourly time series simulation for every possible system configuration on a yearly basis in order to evaluate the operational characteristics such as annual electricity production, annual load served, excess electricity, renewable fraction and so on. The renewable energy sources and diesel load generator were evaluated in order to determine the feasibility of the system. HOMER searched for optimum system configuration and component sizes that meet the load requirement at the lowest Cost (NPC) and then presents the results of the simulation in terms of optimal systems and sensitivity analysis.

The optimal results are categorized based on tilt sensitivity variables chosen. Table 6 shows the system architecture in terms of kW rating of the array, wind turbine, diesel generator and the converter. The number of batteries required for energy storage is also indicated under the system architecture. The conventional stand-alone diesel generator is presently employed in most rural areas in Nigeria, and hence considered as the base case simulation in this work. It is selected to allow a comparison to be made about the total savings that can be made by including a renewable energy source in the system design and implementation of hybrid power system (i.e. comparing cost and emissions of DC with the proposed hybrid PV/wind/diesel/converter configuration).

PV/diesel/battery/converter configuration is adjudged the optimal best in Ikpa Road, Abraka, Edibe Edibe, Okada and Wind/diesel/battery/converter configuration is adjudged the optimal best in Iwofe and Wilberforce island, and hence compared to the base case simulation with respect to NPC, RF, carbon emissions and diesel consumption for the diesel price (\$0.56/l).

A. Total NPC Calculations

The NPC of all the feasible system configurations considered for implementation of hybrid power system of the selected sites are illustrated for diesel price of \$0.56/ l. NPC is calculated for the entire system based on the expected life of 20 years. The system configuration includes: Wind/ Diesel/ Battery/ converter, PV/ Wind/ Diesel/ Battery/ converter, Diesel/ Battery/converter, PV/ Diesel/ Battery/ converter, PV/ Wind/ Battery/ converter, Diesel Standalone, Wind/ Diesel, PV/ Diesel/ converter, PV/ Wind/ Diesel/ converter, PV/ Battery/ converter, as results are shows in Table 5.

From the NPC analysis, it can be observed that stand-alone PV/Wind/diesel/battery/ converter system has the lowest NPC among the studied configuration for all the location when considering the average total NPC of each configuration in table 5. This study will be comparison will be mostly on Hybrid PV/Wind/ Diesel/ Battery/ Converter system configuration. The wind system is not the best option because of the low wind speed at most of the sites. Fig.13 and 14 show the graphical representation of NPC and COE respectively for PV/Wind/diesel/battery systems for all sites. In all the case of NPC calculation, \$1 ₦356, where \$ is US Dollars and ₦ is Nigerian currency in Naira.

The lowest 'NPC is obtained in Wilberforce Island, found in the tropical monsoon climatic zone. At \$0.56/L, the NPC is \$464240 and COE is \$1.03/kwh. The result shows the direct relationship between NPC and the level of components resources(solar radiation and wind speed), The higher the solar radiation in a site, the lower will be the NPC value, The higher the wind speed in a site, the lower will be the NPC value, This is because high irradiation will enable the PV system to supply the load for a longer period, thereby reducing the operating hours of the diesel generator; this will bring about reduction in the diesel consumption and cost associated with diesel, which thus relates directly to low NPC.

Iwofe in the tropical wet climate is next to Wilberforce Island with value of \$464248, followed by Abraka which stands at \$507588NPC.

The difference in average solar radiation and wind speed between these sites is found to be minimal. Okada, which represents the tropical climate, showed the highest NPC out of the six sites considered in the simulation. This is attributable to the low average daily global wind speed as found in this site compared to Wilberforce Island and Iwofe daily wind speed. The total NPC of Okada is \$519876; when compared to the base case NPC (i.e. diesel generator only), a saving of \$347, 050 can be achieved.

B. System Architecture

Table 6 presents the number of components selected for most feasible configuration (PV/Wind/diesel/battery) in each state in south region of Nigeria, based on \$0.56/L diesel price considered. HOMER considered many factor such as global solar irradiation, global wind speed, diesel prices as well as load profile in coming up with this optimized number of system components. The component optimization process prioritizes continuous meeting of load demands by the hybrid system. This is aimed at ensuring marginal diesel consumption as well as making sure that PV system and wind turbine is not oversized. The space requirement for installation is also considered in the sizing of the batteries component.

The smallest component sizing in system architecture was obtained at Wilberforce Island out of all the sites considered. The system architecture includes 0.59 kW solar panel, a 17 kW generator, a 10.5 kW converter and 64 batteries. It was noted from the simulation that most of the sites considered except Edibe Edibe, reported increase in the size of PV panel and batteries bank. This justifies the extra costs of installing a larger PV array and increasing the storage capabilities of the system in order to minimize the operating hours of the generator, thus keeping the NPC as low as possible.

C. RF Calculations

Renewable fraction varies as the system architectures for each site considered in the simulation. It can be observed from (Fig. 15) that RF for each site in the simulation is notably high for sensitivity case of \$0.56/l. Out of the six sites considered, Iwofe, Wilberforce and Edibe Edibe experience high RF value, the values are 0.29,0.26,0.22at \$0.56/L respectively.

The lowest RF of 0.19 occurs in Okada for sensitivity case of \$0.56/l. Ikpa road and Abraka also experience a relatively low RF of 0.20 and 0.21 respectively for diesel price of \$0.56/l.

D. Carbon Emissions and Diesel Consumption

Annual CO2 emissions relate directly to the amount of liters' fuel consumed by the diesel generator per year. Fig. 15 shows a comparison to the total amount of diesel consumed per year by PV/diesel/battery configuration for each site with base case simulation at diesel price \$0.56/l.

Co₂ Emissions in kg/yr for the sensitivity cases at each site are shown in – Iwofe site consumed the least volume of diesel per year (9713L at diesel price \$0.56/l), while the highest volume of diesel consumption is observed at Okada.

Comparing Fig 16 and Fig. 23: It shows that the hybrid renewable energy system configuration, provide a greater savings in CO₂ emission as the lower the volume of fuel consumed, the lower the CO₂ emitted (diesel generator system). Iwofe displays the lowest amount of CO₂ emission (25424.88 kg/yr). Followed by Wilber force island (26770.56 kg/yr). The highest value of Co2 emissions occurred at Okada, which stands at 28716.36 kg/yr for the sensitivity case of \$0.56/l.

E. Electrical Summary

Wilberforce Island has the highest excess electricity of 2310.9kWh/yr which is 4.1% of total production as shown in table 7 while Iwofe follows as second highest with excess electricity of 2172.6kWh/yr which is 3.9% of total production while Okada has lowest excess electricity quantity of 84.1kWh/yr which is 0.2% of total production

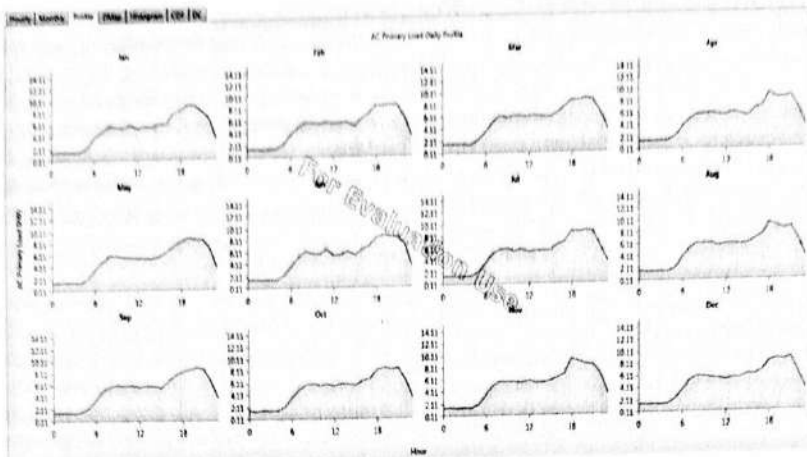


Figure 4.0: Monthly AC Primary Load Profile

TABLE II
ESTIMATED ELECTRICITY DEMAND FOR EACH RURAL COMMUNITY

Load	No in use	Power (watt)	January to December	
			(hr/day) (watt-hr/day)	
Category A: Domestic load				
Lighting	4	20	8	640
Television	1	80	4	320
Radio	1	10	12	120
Ceiling fan	2	0	18	1080
Total for 50 household				108000
Category B: Social infrastructural Load				
• Primary health center				
Lighting (CFL)	6	20	10	1200
Refrigerator	1	16	6	960
Television	1	600	6	480
Ceiling fan	2	80	12	720
Total		30		12000
• Public primary school				
Lighting (CFL)	7	20	4	560
Ceiling fan	1	6	6	180
Total		30		740
• Community hall and shops				
Lighting	10		5	1000
Ceiling fan	4	20	7	840
Television	1	30	6	480
Total load		30		2320
Miscellaneous load		80	6	480
Total load consumption		80		123540

TABLE III
SOLAR IRRADIATION DATA FOR THE SIX VILLAGES (KWH/M²/DAY)

Month	Village					
	Iwofe	Wilberforce Island	Ikpa Road	Okada	Edibe Edibe	Abraka
January	5.14	5.19	5.47	5.37	5.55	5.27
February	5.18	5.19	5.53	5.43	5.59	5.27
March	4.74	4.82	5.25	5.28	5.28	5.12
April	4.53	4.78	5.02	4.99	5.02	4.98
May	4.16	4.31	4.65	4.67	4.71	4.48
June	3.48	3.53	4.24	4.16	4.29	3.69
July	3.19	3.22	3.79	3.51	3.83	3.25
August	3.37	3.45	3.71	3.51	3.63	3.76
September	3.63	3.54	4.22	4.33	4.27	4.21
October	3.63	3.54	4.22	4.33	4.27	4.21
November	4.16	4.33	4.79	4.94	4.79	4.92
December	4.90	4.97	5.23	5.19	5.27	5.08
Average	4.176	4.239	4.677	4.643	4.708	4.520

Port Harcourt

Average and Max Wind Speed and Gust (mph)
 Zoom 1m 3m 6m YTD 1y All

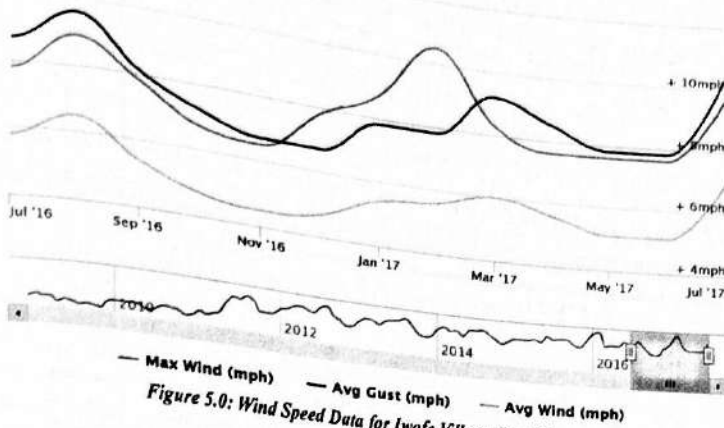


Figure 5.0: Wind Speed Data for Iwofe Village, Port Harcourt.

TABLE IV
 WIND SPEED DATA FOR THE SIX VILLAGES

Month	Villages					
	Iwofe	Wilberforce Island	Ikpa Road	Okada	Edibe Edibe	Abraka
January	5.4	5.4	3.6	3.4	3.6	4.3
February	5.6	5.6	3.8	3.1	3.6	4.3
March	6.0	6.0	4.0	3.8	3.8	4.5
April	5.6	5.6	4.0	3.6	4.0	4.5
May	5.1	5.1	3.6	3.6	3.6	4.0
June	5.1	5.1	3.4	3.1	3.1	3.8
July	5.8	6.9	4.0	3.6	3.6	4.7
August	6.5	6.5	3.6	4.0	3.4	4.9
September	5.4	5.4	3.4	3.4	3.1	4.3
October	4.7	4.7	3.4	3.1	3.4	4.0
November	4.5	4.5	3.1	2.9	3.1	3.6
December	4.7	4.7	3.1	2.9	3.1	3.6
Average	5.37	5.46	3.58	3.38	3.45	4.21

TABLE V
 NPC SIMULATION FOR ALL SYSTEM CONFIGURATION

System Configuration	Iwofe	Wilberforce Island	Ikpa Road	Okada	Edibe Edibe	Abraka	AVG. NPC
Wind/Diesel/Battery/converter	461369	459127	525469	528556	529358	519966	503974.2
PV/Wind/Diesel/Battery/converter	464248	464240	517604	519876	519033	507588	498764.8
Diesel/Battery/converter	510692	510692	510783	510783	510783	510588	510720.2
PV/Diesel/Battery/converter	513791	515055	502787	501767	502346	502576	506387
PV/Wind/Battery/converter	805118	767250	907906	915547	904874	886196	864481.8
Diesel	866926	866926	866926	866926	866926	866926	866926
Wind/Diesel	869541	869540	891667	891867	891816	890900	884221.8
PV/Diesel/converter	887894	888215	869537	869537	869537	869537	875709.5
PV/Wind/Diesel/converter	906534	906857	910273	910470	910420	909518	909012
PV/Battery/converter	1050000	1040000	898405	908390	893987	957751	958088.8
Wind/Battery/converter	1190000	1120000	N/A	N/A	N/A	2260000	-

Select Base Case

Choose a base case to compare with other systems for economic analysis. More detailed economic comparison is available in Simulation Results.

☑ Categorized ☑ Overall

Architecture				Cost				System		Gen							
PV (kW)	Gen (kW)	12VWH LA (V)	Converter (kW)	Dispatch (V)	COE (\$)	NPC (\$)	Operating cost (\$)	Initial capital (\$)	Ren frac (%)	Hours	Production (kWh)	Fuel (\$)	OBM Cost (\$)	Fuel Cost (\$)	Capital Cost (\$)	Product (kWh)	
0.986	1.00	170	88	11.3	CC	\$1.14	\$555,081	\$48,881	0.0	3,497	56,534	14,940	29,724	9,486			
0.986	1.00	170	88	11.2	CC	\$1.14	\$558,199	\$48,889	0.0	3,458	54,607	16,415	29,797	9,293			
0.188	1.00	1	170	84	11.4	CC	\$1.18	\$574,133	\$50,381	0.0	3,384	54,952	16,414	28,764	9,209		
0.188	1.00	1	170	88	11.0	CC	\$1.18	\$577,139	\$50,103	0.0	3,353	55,007	16,413	28,764	9,209		
0.242	1.00	170			CC	\$1.94	\$844,175	\$87,058	\$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.242	1.00	170		0.0906	CC	\$1.94	\$847,007	\$87,290	\$3,018	0.0	8,760	54,761	20,591	74,460	11,531		
0.340	1.00	1	170		CC	\$1.90	\$971,018	\$88,984	\$8,281	0.0	8,760	54,054	20,499	74,460	11,479		
0.340	1.00	1	170		549	LI	\$2.03	\$988,756	\$90,022	\$14,771	0.0	8,760	53,755	20,339	74,460	11,390	

Figure 6.0: NPC for Diesel Price Of \$0.56/1 for System Configuration for Ikpa Road

Select Base Case

Choose a base case to compare with other systems for economic analysis. More detailed economic comparison is available in Simulation Results.

☑ Categorized ☑ Overall

Architecture				Cost				System		Gen					PV	
PV (kW)	Gen (kW)	12VWH LA (V)	Converter (kW)	Dispatch (V)	COE (\$)	NPC (\$)	Operating cost (\$)	Initial capital (\$)	Ren frac (%)	Hours	Production (kWh)	Fuel (\$)	OBM Cost (\$)	Fuel Cost (\$)	Capital Cost (\$)	Product (kWh)
1.21	170	80	12.4	CC	\$1.08	\$482,110	\$42,142	\$43,077	0.0	2,354	36,280	10,950	20,009	6,132	\$6,448	18,857
11.5	170	80	13.6	CC	\$1.33	\$498,972	\$43,345	\$48,386	2.0	2,304	36,208	10,843	19,584	6,072	\$4,511	17,855
11.5	170	84	11.5	CC	\$1.12	\$499,869	\$47,364	\$29,364	0.0	3,392	56,820	16,699	30,532	9,292		
0.242	170			CC	\$1.94	\$868,928	\$87,043	\$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.242	170		0.0906	CC	\$1.94	\$869,535	\$87,229	\$3,018	0.0	8,760	54,759	20,591	74,460	11,531	727	776
1.71	170			CC	\$1.99	\$881,867	\$88,949	\$8,261	0.0	8,760	54,177	20,445	74,460	11,449		
1.71	170	448	13.0	CC	\$2.03	\$892,442	\$66,625	\$230,599	100						150,363	77,793
36.4	170		0.0414	CC	\$2.03	\$910,467	\$60,302	\$13,419	0.0	8,750	54,057	20,415	74,460	11,432	\$1,516	2,647
36.4	170	352	14.7	CC	\$2.10	\$924,457	\$68,616	\$242,838	100						169,345	87,824

Figure 7.0: NPC for Diesel Price of \$0.56/1 for System Configuration for Okada

Select Base Case

Choose a base case to compare with other systems for economic analysis. More detailed economic comparison is available in Simulation Results.

☑ Categorized ☑ Overall

Architecture				Cost				System		Gen					PV	
PV (kW)	Gen (kW)	12VWH LA (V)	Converter (kW)	Dispatch (V)	COE (\$)	NPC (\$)	Operating cost (\$)	Initial capital (\$)	Ren frac (%)	Hours	Production (kWh)	Fuel (\$)	OBM Cost (\$)	Fuel Cost (\$)	Capital Cost (\$)	Product (kWh)
11.6	170	80	10.4	CC	\$1.16	\$438,857	\$44,890	\$36,540	1.8	2,461	37,007	11,239	20,918	6,294	\$4,875	17,399
11.3	170	80	10.7	CC	\$1.11	\$448,556	\$43,157	\$64,788	2.0	2,329	34,915	10,548	19,796	5,829	\$3,877	16,802
17.0	170	84	12.5	CC	\$1.13	\$460,548	\$48,243	\$24,364	0.0	3,824	56,757	17,085	30,804	9,568		
17.0	170	88	12.8	CC	\$1.13	\$469,149	\$49,109	\$34,282	0.0	3,310	53,977	16,542	28,133	9,099		
0.242	170			CC	\$1.99	\$1,198	\$87,057	\$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.242	170		0.0906	CC	\$1.94	\$1,184	\$87,250	\$3,018	0.0	8,760	54,761	20,591	74,460	11,532	727	362
1.71	170		0.0414	CC	\$2.09	\$1,184	\$90,303	\$13,419	0.0	8,760	53,991	20,247	74,460	11,338		2,593
35.3	170	552	14.9	CC	\$2.10	\$1,394	\$85,913	\$282,802	100						153,759	78,712
68.7	170	712	16.1	CC	\$2.78	\$1,613	\$99,043	\$309,130	100						206,274	102,861
78	170	992	22.4	CC	\$3.99	\$3,479	\$228,702	\$439,196	100							182,861

Figure 8.0: NPC for Diesel Price of \$0.56/1 for System Configuration for Abraka

Select Base Case

Choose a base case to compare with other systems for economic analysis. More detailed economic comparison is available in Simulation Results.

☑ Categorized ☑ Overall

Architecture				Cost				System		Gen					PV		
PV (kW)	Gen (kW)	12VWH LA (V)	Converter (kW)	Dispatch (V)	COE (\$)	NPC (\$)	Operating cost (\$)	Initial capital (\$)	Ren frac (%)	Hours	Production (kWh)	Fuel (\$)	OBM Cost (\$)	Fuel Cost (\$)	Capital Cost (\$)	Product (kWh)	
0.442	4	170	80	21.0	CC	\$1.03	\$500,084	\$40,623	\$60,968	2.8	2,165	34,317	10,310	18,402	5,773	1,326	
0.442	4	170	72	21.0	CC	\$1.03	\$500,289	\$40,674	\$58,059	2.2	2,268	35,225	10,618	19,278	5,846		
0.446	170	72	23.3	CC	\$1.12	\$548,219	\$47,495	\$94,348	0.0	3,352	57,229	17,550	30,192	9,404			
0.446	170	88	21.0	CC	\$1.13	\$550,058	\$47,339	\$37,859	0.0	3,414	56,200	16,781	29,019	9,398	1,399	643	
0.000154	170			CC	\$1.94	\$846,132	\$87,239	\$2,261	0.0	8,760	54,840	20,611	74,460	11,542			
0.000154	170		0.240	CC	\$1.94	\$846,751	\$87,274	\$2,261	0.0	8,760	54,840	20,611	74,460	11,542	0.5	0.2	
0.310	170			CC	\$1.99	\$868,863	\$88,785	\$8,261	0.0	8,745	52,301	19,962	74,332	11,279			
0.310	2	170		0.0579	CC	\$2.02	\$987,077	\$89,823	\$15,250	0.0	8,634	50,465	19,414	73,389	10,872	931	429
55.4	4		440	14.4	CC	\$2.34	\$1,184	\$80,409	\$270,557	100					166,132	76,345	
71.7		720	19.2	CC	\$2.97	\$1,454	\$102,093	\$342,374	100						215,129	98,862	
32		1,208	14.1	CC	\$3.80	\$1,854	\$135,280	\$387,328	100							185,522	

Figure 9.0: NPC for Diesel Price of \$0.56/1 for System Configuration for Iwofe

Select Base Case

Choose a base case to compare with other systems for economic analysis. More detailed economic comparison is available in Simulation Results.

☑ Categorized ☑ Overall

Architecture				Cost				System		Gen					PV	
PV (kW)	Gen (kW)	12VWH LA (V)	Converter (kW)	Dispatch (V)	COE (\$)	NPC (\$)	Operating cost (\$)	Initial capital (\$)	Ren frac (%)	Hours	Production (kWh)	Fuel (\$)	OBM Cost (\$)	Fuel Cost (\$)	Capital Cost (\$)	Product (kWh)
13.4	170	80	11.4	CC	\$1.04	\$467,237	\$41,875	\$45,899	2.8	2,194	34,307	10,312	18,966	5,766	\$6,276	20.88
12.6	170	88	10.1	CC	\$1.29	\$613,131	\$49,493	\$29,330	0.0	3,496	54,377	16,842	29,206	8,412		
12.6	170	80	11.4	CC	\$1.08	\$468,815	\$43,280	\$48,307	2.4	2,204	34,321	10,341	18,734	5,792	\$7,668	18.5
12.6	170	88	10.2	CC	\$1.05	\$433,979	\$46,361	\$31,669	0.0	3,355	53,016	16,488	28,134	9,205		
0.242	170			CC	\$1.93	\$1,194	\$87,057	\$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.242	170		0.0906	CC	\$1.94	\$1,184	\$87,249	\$3,018	0.0	8,760	54,760	20,591	74,460	11,531	727	377
1.71	170		0.0414	CC	\$1.99	\$1,184	\$90,021	\$13,419	0.0	8,760	54,054	20,435	74,460	11,444		
35.2	170	748	14.6	CC	\$2.53	\$1,484	\$81,597	\$297,437	100						165,666	85.8
35.2	170	792	15.1	CC	\$2.34	\$1,484	\$92,074	\$299,362	100						165,522	85.8

Figure 10.0: NPC for diesel price of \$0.56/1 for System configuration for Edibe Edibe

Architecture										Cost										System										Gen									
PV (kW)	WT (kW)	Com (kW)	280V LA	Consumer (kW)	Dispatch	CC (€)	NPC (€)	Operating cost (€)	Initial capital cost (€)	Base Price (%)	Hours	Production (kWh)	Fuel Cost (€)	OB&M Cost (€)	Fuel Cost (€)	Capital Cost (€)	Prod (€)	NPV (€)	IRR (%)	Payback (yr)	NPV (€)	IRR (%)	Payback (yr)	NPV (€)	IRR (%)	Payback (yr)	NPV (€)	IRR (%)	Payback (yr)										
0.212	4	170	72	206	CC	\$0.948	\$932,411	\$19,008	\$47,893	24	2,254	34,383	10,291	18,159	5,819																								
0.289	170	88	975	904	CC	\$1.09	\$614,285	\$41,548	\$48,150	34	2,272	34,084	10,238	18,312	5,787																								
0.242	170			904	CC	\$1.07	\$624,302	\$46,301	\$29,742	60	1,550	35,993	16,638	30,175	9,425																								
1.71	1	170		904	LF	\$1.93	\$1,138	\$67,027	\$2,261	00	6,760	\$4,842	20,911	74,492	11,542																								
42.2	5			904	LF	\$1.96	\$1,154	\$68,639	\$1,818	00	6,760	\$4,762	20,191	74,499	11,531																								
66.2				744	LF	\$2.10	\$1,224	\$69,009	\$18,439	00	6,740	\$2,271	19,954	74,366	11,176																								
	31			976	LF	\$2.82	\$1,644	\$75,579	\$247,352	100																													
				341	LF	\$3.27	\$1,904	\$100,953	\$335,201	100																													
									\$46,301	100																													

Figure 11.0: NPC for Diesel Price of \$0.56/l for System Configuration for Wilberforce Island

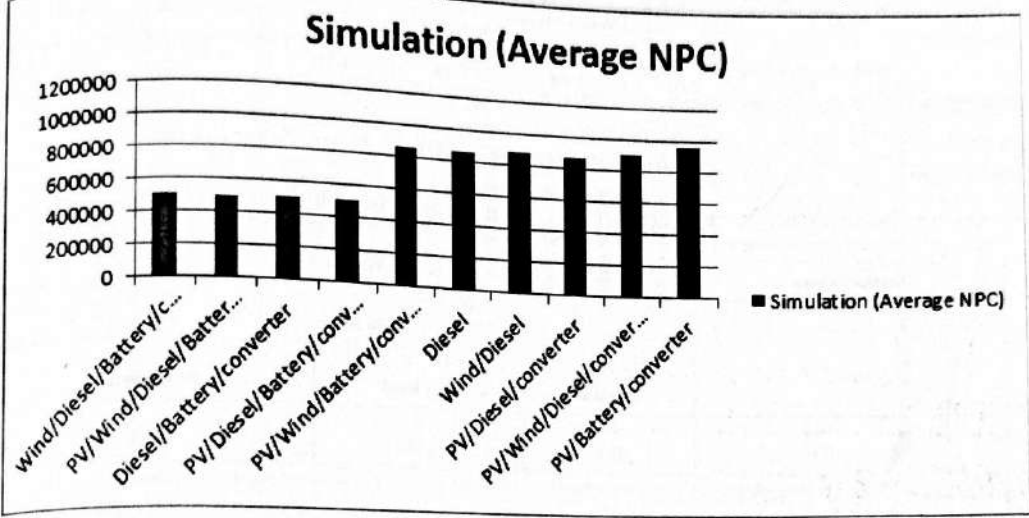


Figure 12.0: NPC for Diesel Price of \$0.56/l for 10 System Configurations

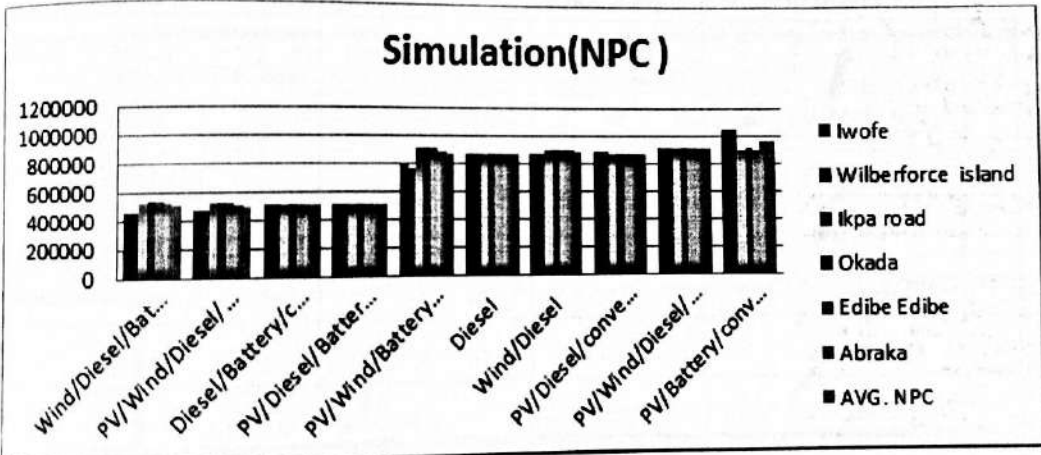


Figure 13.0: NPC for All Location and 10 System Configurations

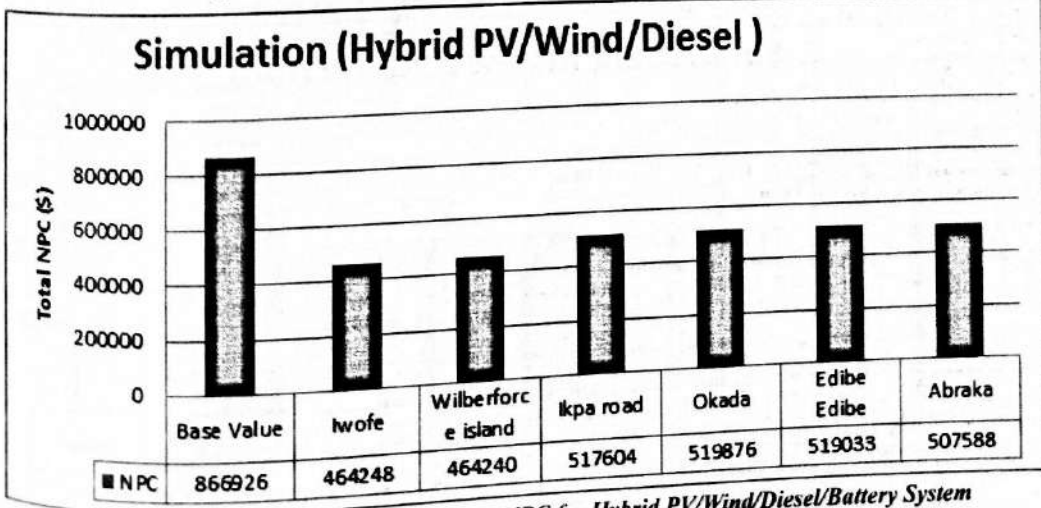


Figure 14.0: Graphical Representation of NPC for Hybrid PV/Wind/Diesel/Battery System

Simulation (Hybrid PV/Wind/Diesel/Battery System)

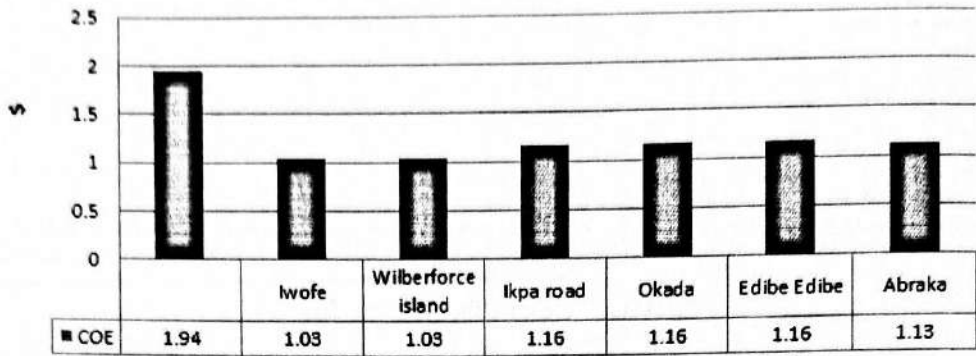


Figure 15.0: Graphical Representation of COE for Hybrid Power System

TABLE VI
SYSTEM ARCHITECTURE FOR CALCULATIONS FOR HYBRID PV/WIND/DIESEL/BATTERY/CONVERTER

Sensitivity case	Villages		
	\$0.56/L		
	Abraka	Ikpa Road	Wilberforce
PV array (kw)	10.8	11.2	0.590
Generator (kw)	17	17	17
Wind turbine (kw)	1	1	4
Converter (kw)	13.8	12.2	10.5
Number of batteries	80	80	64
	Okada	Iwofe	EdibeEdibe
PV array (kw)	11.2	1.89	11.9
Generator (kw)	17	17	17
Wind turbine (kw)	1	4	1
Converter (kw)	13.2	12.2	11.4
Number of batteries	88	72	88

Simulation(Renewable Fraction)

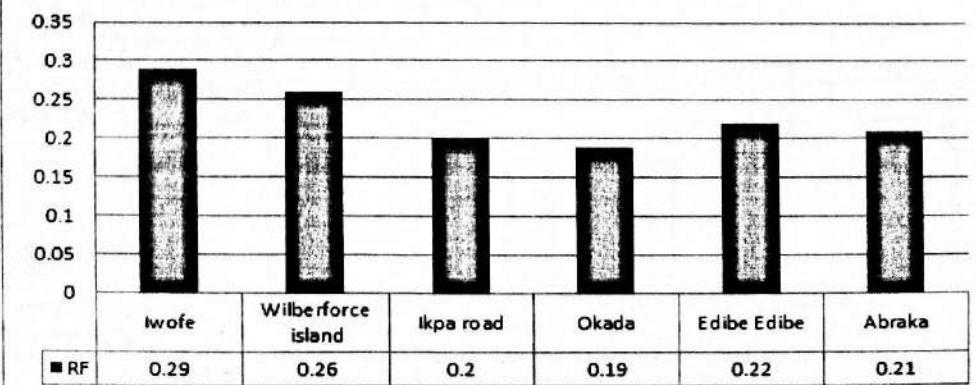


Figure 16.0: RF for Diesel Price of \$0.56

Simulation (Total Fuel Consumed)

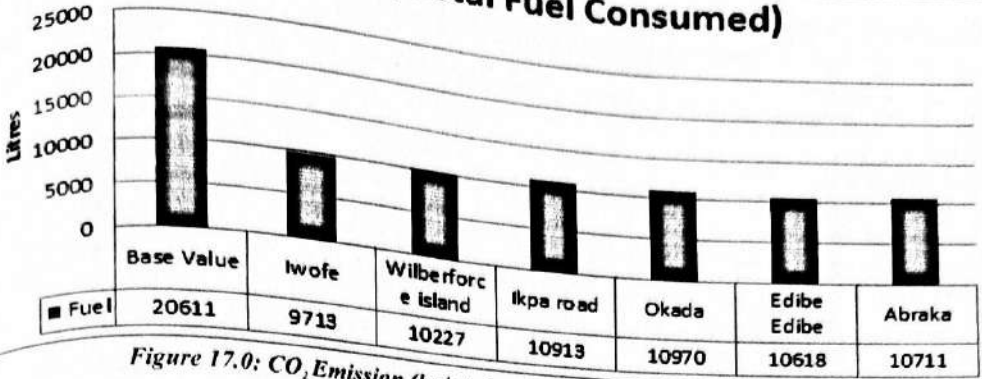


Figure 17.0: CO₂ Emission (kg/yr) for Diesel Price of \$0.56/l for Abruka

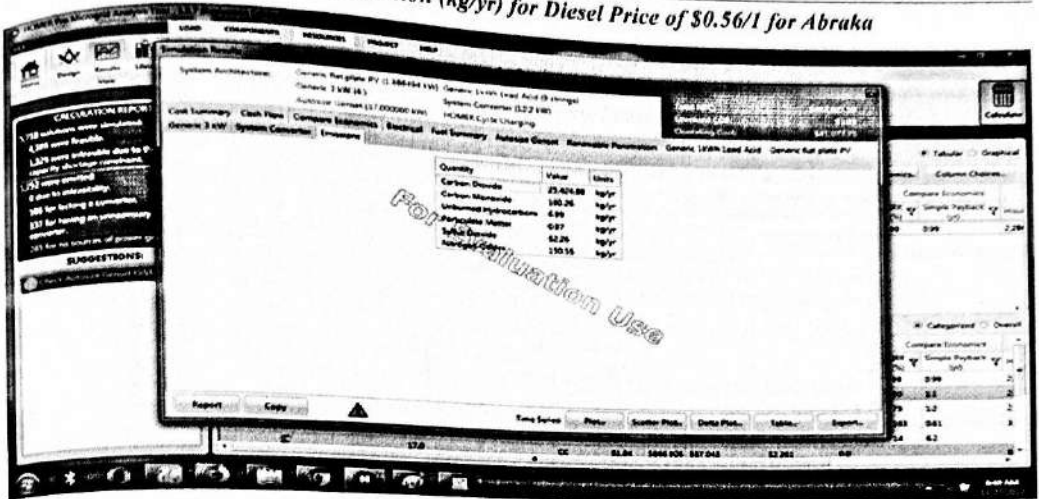


Figure 18.0: CO₂ Emission (kg/yr) for Diesel Price of \$0.56/l for Iwofe

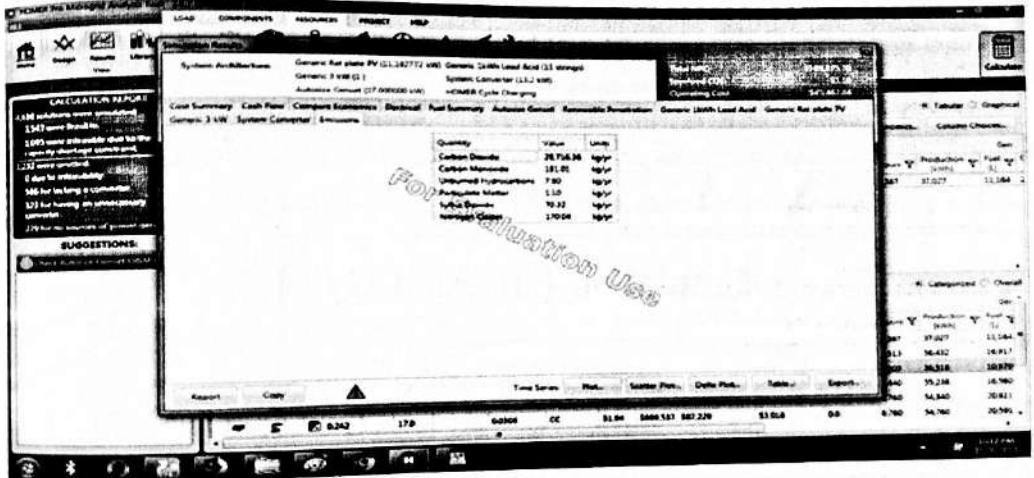


Figure 19.0: CO₂ Emission (kg/yr) for Diesel Price of \$0.56/l for Okada

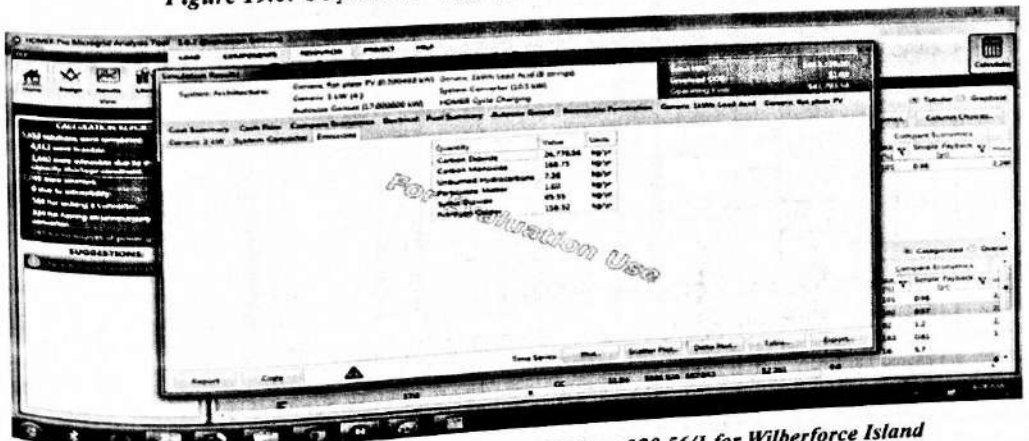


Figure 20.0: CO₂ Emission (kg/yr) for Diesel Price of \$0.56/l for Wilberforce Island

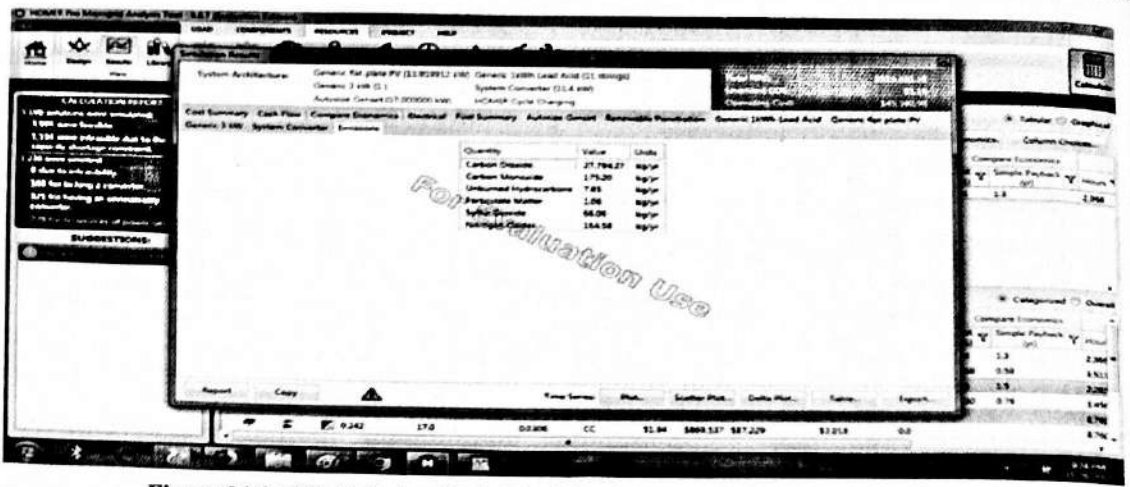


Figure 21.0: CO₂ Emission (kg/yr) for Diesel Price of \$0.56/l for Edibe Edibe

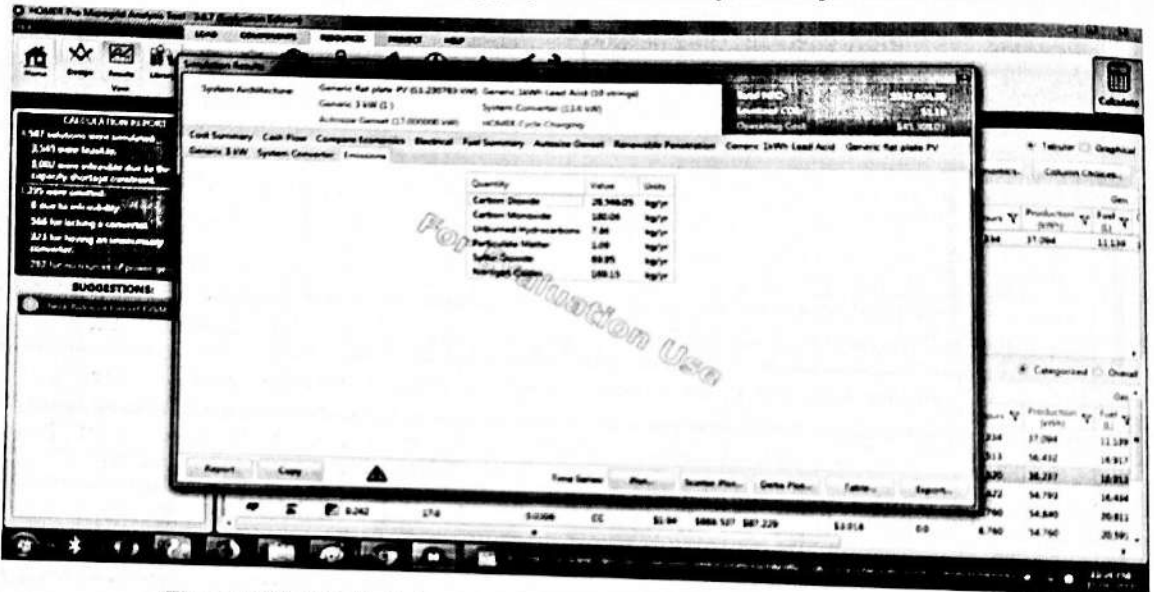


Figure 22.0: CO₂ Emission (kg/yr) for Diesel Price of \$0.56/l for Ikpa road

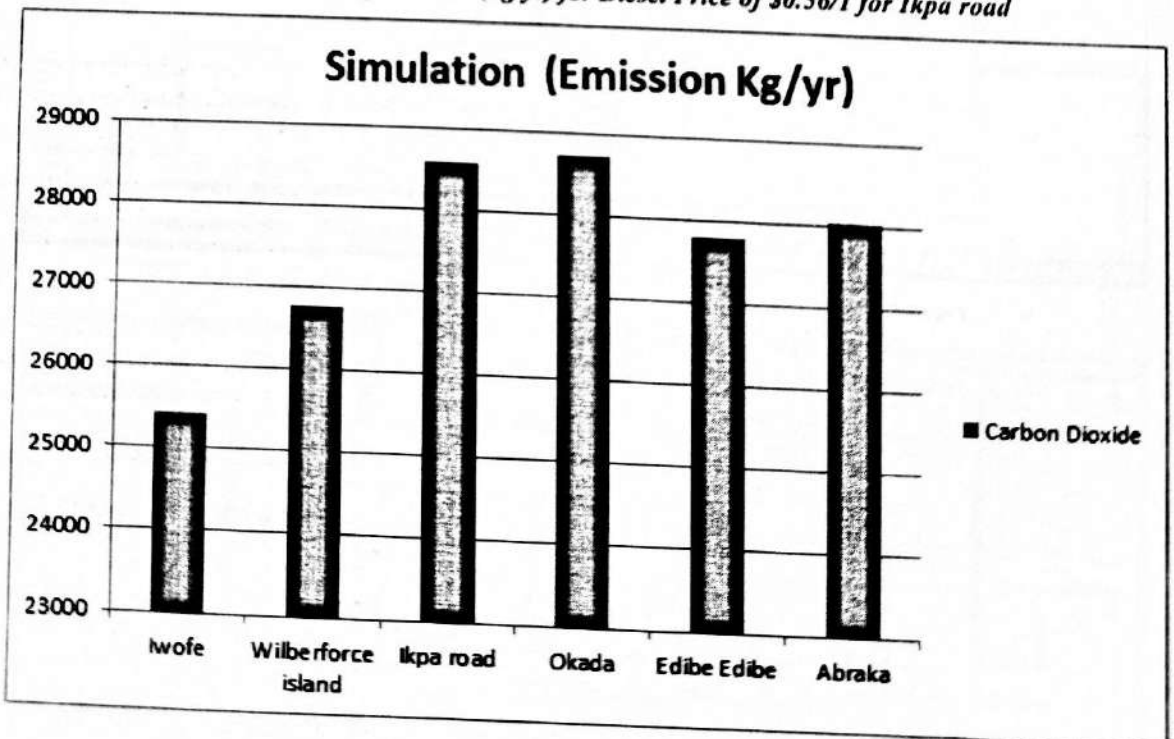


Figure 23.0: CO₂ Emission (kg/yr) for Diesel Price of \$0.56/l.

ELECTRICAL SUMMARY OF HYBRID PV/WIND/DIESEL/BATTERY/CONVERTER SYSTEMS

Electrical	Abraka	Edibe Edibe	Okada	Ikpa Road	Wilberforce Island	Iwofe
Generic flat plate PV(kWh/yr)	16704	18417	17299	17351	911	2907
Autosize Genset(kWh/yr)	35593	35184	36518	36237	33245	31982
Generic 3Kw(kWh/yr)	2550	1217	4133	1414	21532	21066
Total(kWh/yr)	54847	54818	54950	55002	55688	55955
AC Primary load (kWh/yr)	45092	45092	45092	45092	45092	45092
Excess Electricity	210.9	175.9	84.1	178.5	2310.9	2172.6
Renewable Fraction	21.1	22	19	19.6	26.3	29.1

CONCLUSION

VI. In this research paper, the techno-economic feasibility of hybrid power systems in six selected sites picked from each state of the south-south region of Nigeria was conducted. Through investigation of resources availability in each state and simulations of the total system scenarios, the optimum system architecture, total costs and environmental impacts, were quantitatively analyzed. Ten system configurations including: Wind/Diesel/Battery/converter, PV/Wind/ Diesel/Battery/converter, Diesel/Battery/converter, PV/Diesel/Battery/converter, PV/Wind/Battery/ converter, Diesel Standalone, Wind/Diesel, PV/Diesel /converter, PV/Wind/Diesel/converter, PV/Battery/ converter were considered by HOMER to obtain the most economically feasible solution. According to the results for the selected sites in this study, it can also be concluded that:

The PV/wind/diesel/battery/Converter hybrid renewable system configuration is found as optimum architecture for sensitivity cases of \$0.56/l, based on the NPC. COE and RF calculation if uniform standard is applied for same system configuration to be installed in all of the state. In addition, the best optimum location to install a PV/wind/diesel/battery/ converter power system in southern region of Nigeria is Wilberforce Island in the tropical monsoon climatic zone.

The overall results indicated that not only does the hybrid system configuration perform better than base case simulation with regards to the NPC for all six simulations; it also displayed better performance in the categories such as electrical, fuel consumption and CO₂ reduction.

The best system configuration with the lowest NPC for each state include Iwofe to use Wind/ Diesel/ Battery/ Converter system, Wilberforce Island to use Wind/ Diesel/ Battery/ Converter system, Ikpa road to use PV/Diesel/ Battery/ Converter system, Abraka to use to use PV/ Diesel/ Battery/ Converter system, Edibe Edibe to use to use PV/ Diesel/ Battery/ Converter system, Okada to use to use PV/ Diesel/ Battery/ Converter system.

REFERENCES

[1] S.B, Kjaer, J.K. Peperson F. Blaabjerg. "A review of single transactions on Industry Applications, September/October, Vol. 41, No 5, 2005, PP. 1292 – 1306.

- [2] I. Sefa, N. Altin "Simulation of current controlled grid interactive Inverter" TPE – 2006 3rd conference on Technical and Physical Problems in Power Engineering, Ankara (Turkey), May 2006, PP. 964 – 968. 9
- [3] U.S. Emission Data, Environment Energy – Related Emission Data & Environmental Analysis, Energy Information Administration (<http://www.eia.doc.gov/environment.html>/access date 10 April 2011).
- [4] Nnaji, C. Uzoma, C. Chukwu, J. The role of renewable energy resources in poverty alleviation and sustainable development in Nigeria. *Cont J SocSci*2010;3:317. sustainable development in Nigeria. *Cont J SocSci*2010;3:317.
- [5] Kaldellis, J. K. Zafirakis, D. Kaldelli, E. L. Kavadias. K. Cost benefit analysis of a photovoltaic-energy storage electrification solution for remote islands. *Renew Energy* 2009;34(5):1299311.
- [6] Bajpai, P. Dash, V. Hybrid renewable energy systems for power generation in stand-alone applications: a review. *Renew Sustain Energy Rev* 2012;16 (5):2926/39.
- [7] Hiendro A, Kurnianto R, Rajagukguk M, Simanjuntak. Y.M. Techno-economic analysis of photovoltaic/wind hybrid system for onshore/remote area in Indonesia. *Energy* 2013;59:652.
- [8] IFAD. Enabling poor rural people to overcome poverty in Nigeria, international fund for agricultural Development. 2012. Journal of Solar Energy Volume 2015 (2015). Article ID 819307, 9 pages. Available from: <http://dx.doi.org/10.1155/2015/819307>.
- [9] Sambo, A.S Strategic developments in renewable energy in Nigeria. *Int. Assoc. Energy Econ* 2009:15-9.
- [10] Chaurey, A. Kandpal, T.C. Assessment and evaluation of PV based decentralized rural electrification: an overview. *Renew Sustain Energy Rev* 2010;14(8):2266-78.
- [11] Sen, R. Bhattacharyya, S.C. Off-grid electricity generation with renewable energy technologies in India: an application of HOMER. *Renew Energy* 2014;62:388-98.

- [12] Mohammed, Y.S. Mustafa, M. W. Bashir, N. Mokhtar, A.S. Renewable energy resources for distributed power generation in Nigeria: a review of the potential. *Renew Sustain Energy Rev* 2013;22:257-68.
- [13] Lambert, T. Gilman, P. Lilienthal, P. Micro power system modeling with HOMER. *Integration Altern Sources Energy* 2006;1 (1):379-85.
- [14] Solar Electricity Handbook Available from: <https://www.solarelectricityhandbook.com/solar-irradiance.html>
- [15] Time and Date Weather global database. Available from: <http://www.timeanddate.com/weather/Nigeria>.