Techno-Economic Design And Integration of Sustainable Hybrid PV/Wind/Diesel Turbine Generation Into The Nigerian Power System

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Abstract: Electricity supply that is effective, dependable, and reasonably priced is a key component of economic success in every nation. With an estimated population of 200 million, Nigeria is one of the nations in the West African sub-region. Only 45% of them have a connection to electricity. The projected 7MW total grid generation capacity currently powers residential regions as well as commercial, industrial, social, as well as institutional centers. This is utterly insufficient for real development. Based on this, the goal of this research is to integrate and diversify the power industry in order to utilize all available energy sources, including renewable ones. The goal of the study "Techno-economic design as well as the incorporation of environmentally friendly Hybrid PV/Wind/Diesel Turbine generation into the Nigerian power system" aims to combine energy sources made up of fossil fuels with renewable (photovoltaic) energy sources in order to produce more energy at a cheaper cost while causing the least amount of environmental damage. A framework for technological, economic, and environmental optimization will be created, added to HOMER, a computer program used to study renewable energy, and implemented on the Nigerian power grid. The study's findings show that a hybrid configuration not only outperforms the base case simulation when put up against the NPC for all six simulations, but also did better in terms of electricity output, fuel efficiency, and CO2 reduction.

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

Received: April 21, 2022. Revised: October 19, 2023. Accepted: November 4, 2023. Published: December 29, 2023.

1. Introduction

Electric power supply is a magic bullet for promoting development in any nation since it is clean, eco-friendly, effective, dependable, and economical. Nigeria needs to close the current gap between its supply and demand for electricity if it is to keep up with other technologically proficient nations that have experienced tremendous economic growth. Nigeria continues to have limited development opportunities because to frequent blackouts or outages caused by a lack of generation capacity as well as suitable transmission and distribution facilities. With the rise in global energy demand, producing clean, affordable, and secure energy is becoming more important. Consequently, a new class of sources of electricity has become more common. The sun and the wind energy are more common alternative energy sources.

In the past, they were employed to provide local loads in isolated regions away from the national grid. They then developed into some of the primary sources [1] [2]. Renewable energy sources can be used alone or in conjunction with the grid. In order to operate well in stand-alone mode, substantial capacity battery groups are typically needed. The process of converting (DC) energy to (AC) energy is crucial because electricity produced by solar or wind energy is transported to the grid. A grid tie inverter was used to accomplish this operation; it serves the local loads and exports any excess energy to the grid if the generated energy is greater than the demand. So battery groups are not needed.

The control grid-tied inverter, however, involves a more involved and independent operation. [2] The electric power generation system, which is made up of grid-connected renewable energy sources, has the capacity to supply the load with electricity around the clock. When compared to a stand-alone system, this system offers greater output performance in terms of dependability, efficiency, planning flexibility, and environmental advantages. The environment is protected from the combustion of fossil fuels with every kilowatt-hour (kWh) produced from renewable energy, according to research. For every 1 KWh of electricity produced, coal-fired power plants and natural gas-fired power plants emit 1.05 kg and 0.75 kg of carbon dioxide, respectively [3].

Over the years, concerns about the ozone layer's thinning and the world's alarming rate of warming have grown. The difficulty with this problem has grown. Fossil fuels are used to produce or provide most of the energy. However, there are some significant disadvantages to using fossil fuels, such as their limited supply, fluctuating pricing, and environmental degradation. In order to address these issues, the integration of renewable energy sources alongside traditional fossil fuel power plants is thought to be a viable alternative. This will boost energy growth, increase energy reliability, and improve environmental health.

The following goals are sought to be accomplished in the study "Design with Techno-Economic and Carbon Credit Optimisation of Grid Hybrid Photovoltaic/Wind/Diesel Power System into the Nigerian Power System Using HOMER" model:

1. Combine fossil fuels with renewable energy sources to create a hybrid system that is more effective and can get over some of the drawbacks of RES, such as intermittency and energy amount. Such hybrid plans can produce a system that is more dependable, sustainable, and environmentally benign. Solar energy technologies stand out among RES technologies for their significant development and level of maturity in power generation. More dependable and environmentally friendly power is produced by the combination with non-renewable sources (Diesel Generator).
2. By taking into account the impact of temperature and solar radiation, it may be possible to precisely anticipate the voltage output from grid-connected photovoltaic arrays. It will be demonstrated how it is feasible to vary the size of models and the various PV hybrid system configurations that are suited to a grid connection in order to gather crucial data on the techno-economic performance of these systems. Once this has been accomplished, a side-by-side evaluation of various grid-connected PV sizes will be carried out. By examining several measured values over the collecting time, such as power output against radiation, voltage relative radiation and output versus radiation, voltage against radiation, and output power versus temperature, the shape of this model will be supported. The magnitude and percentage of the penetration factor for all parameters connecting to the factors should be explained appropriately in these charts.
3. To accurately anticipate the maximum power output from each PV hybrid system size and configuration, the software Hybrid Optimizations Model for Electric Renewable program will be used to analyze the impact of temperature coefficient along with non-linear radiation term. This is possible under normal operating conditions as well as for a single unrealistic value of solar radiation. It is crucial for the deployment of photovoltaic hybrid systems to grow so that the power output can be predicted with accuracy.
4. To identify the obstacles/restraints that must be overcome: Yearly Electrical Power Demand, Reliability, Net Present Cost, Environmental Factors, and Employment. The following hybrid renewable system configurations are in use: Wind/ Diesel/ Battery/ Converter, PV/ Wind/ Diesel/ Battery/ Converter, Diesel/ Battery/ Converter, PV/ Diesel/ Battery/ Converter, PV/ Wind/ Battery/ Converter, Diesel Standalone.
5. To simulate HOMER-based system configuration optimization to satisfy load demand and evaluations based on system life cycle cost and power reliability.

In light of the aforementioned, this research is divided into eight categories. The problem statement, aims, and objectives are included in the first section's introduction to the study. The review of related literature is in Section II. Section 3 presents the approach for the description, component specification, and design of the renewable hybrid system. The system description along with the presentation is included in Section IV. Section V contains a presentation of the data, an analysis of the findings, and a description of the input settings needed to run the HOMER simulation software for the PV/Wind/Diesel hybrid system. Further mentioned was its combination of solar PV/gas/battery operating strategies and aspects of its economic analysis. The conclusion is presented in Section VI.

2. Review of Related Literature

Due to insufficient transmission lines, Nigeria's government efforts to electrify rural areas have stopped, leaving rural areas with an uneven distribution of energy and a relatively low voltage profile. The rural area's potential for future socioeconomic growth has been hampered by the inadequate electrical supply. Additionally, the country's poverty level has increased as a result of the lack of power in rural areas. If implemented with the right legislation, sustainable development technology is one of the tried-and-true solutions for eliminating energy poverty [4]. Over time, RETs have become more widely used to meet the world's energy needs [5].

By lowering greenhouse gas emissions and providing low operating and maintenance costs while meeting the rapidly increasing energy demand, these technologies have proven their ability to make a significant contribution to global climate protection [6]. Solar and wind are two of the most prevalent and easily available renewable energy sources, no matter how distant the area. In this context, a remote location may not only refer to one that is far from the national grid; it may characterize also refer to any site or settlement where expanding the grid network is not practical or cost-effective because of the difficult topography and unfavorable terrain, which primarily characterizes isolated desert areas in Nigeria and other developing nations. Small off-grid independent renewable energy systems are thus an essential option for bridging the energy gap in developing countries rural areas, where grid extension progress is still lagging behind population growth [7]. Describe remote desert locations in Nigeria as well as other poor nations.

According to national statistical authorities, the term "rural population" refers to persons who reside in rural areas. The dismal socio-economic standing of Nigeria's rural villages is clearly a result of the nation's inadequate energy supply. Up to 80% of Nigeria's rural villages, according to the International Fund for Agricultural Development [8], are considered to fall below the poverty level. The cost of purchasing or fueling electricity-generating units is out of reach for many rural company owners and entrepreneurs. The withdrawal of the fuel subsidy by the Nigerian federal government in 2012 made the situation even worse. Many people have given up on their enterprises as a result, out of frustration. These experiences have frequently caused a rural-urban migration shift in these communities when the young and successful adolescents leave the old and frail ones behind and relocate to the metropolis. This has also increased the number of poor people in urban areas, which has caused rural regions to become socially backward and unexplored in terms of their economic potential [9].

Electricity is therefore regarded as one of the essential tools for productivity since the significance of electricity cannot be overstated. A region without access to electricity typically lacks necessary infrastructures like a school, hospital, communication, portable water supply, etc. It has been discovered that electrified communities have higher Human Development Index values than non-electrified communities [10]. Due to the high related costs as well as transmission loss taking into account the distance from the available grid to the load centers, national grid extension via the dense jungles and challenging topography in the majority of villages may be challenging and uneconomical [11].

When properly run and maintained, diesel generators may be a dependable source of electricity for remote villages; but, they can also have a number of drawbacks, notably noise and environmental pollution from the release of CO2 and other toxic chemicals. Due to an unpredicted increase in the price of fuel, which includes higher delivery costs to outlying areas, it can also be difficult to maintain. It is crucial to build an autonomous, off-grid power generation system for rural communities in Nigeria because expanding the national grid to rural areas is not currently seen as a viable option for increasing access to electricity in rural areas. Diesel generators can provide a consistent source of electricity for isolated villages when they are properly operated and maintained, but they can also have certain downsides, including noise and pollution of the environment from the production of CO2 and other hazardous substances. It might also be challenging to maintain due to an unanticipated rise in fuel prices, which includes greater delivery expenses to remote places. Building a self-sufficient, off-grid power generation system is essential for Nigeria's rural communities because increasing the national grid there is not currently viewed as a practical solution for enhancing access to electricity in remote regions.

In conclusion, a survey of related literature demonstrates that an adequate energy supply is essential for the long-term growth of any country's economy. Researchers have previously used a variety of simulation tools in the fields of integration and renewable energy. But in recent years, HOMER has emerged as the most popular and effective modeling optimization tool. It is an advanced tool or computer model that makes it easier to construct standalone electric power systems and runs simulations to meet the specified load demand utilizing different technology choices and resources that are available, which is one of its main advantages over competing software. Based on the hourly time-stepped load data profile and the average monthly weather data for the specified site over the course of a year, HOMER mimics an HPS. The greatest economically and technically viable system for every given climate zone can be simulated using this data, together with the component sizes and prices that are chosen.

3. Methodology Used for Analysis

One of the more popular optimization tools for HPS modeling is the HOMER software. It is a sophisticated tool or computer model that makes it easier to construct standalone electric power systems and runs simulations to meet the specified load demand with available resources and alternative technological possibilities. Based on the hourly time-stepped load data profile and the average monthly weather data for the specified site over the course of a year, HOMER mimics an HPS. HOMER can simulate the best economically and technically viable system for any given climatic zone using this data, the component sizing, and pricing choices.

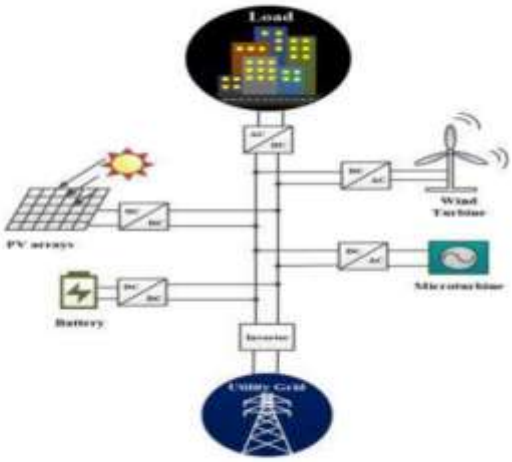


Figure 1: Hybrid PV/Wind/Diesel System with the Battery Storage.

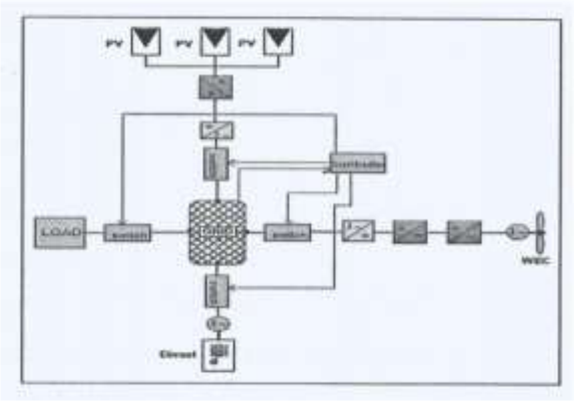


Figure 2: The Modified Distributed Bus AC Architecture

TABLE I:
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
Wilberforce 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
EdibeEdibe	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

3.1. 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.

$$E_{PVG} = G\,(t)\ x A\ x\ P\ x\ n_{PVG} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

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

Where;

$G\,(t)$ = 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:

$$P_m = \tfrac{1}{2} \times p \times A \times V^3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where;

p = air density ($1.225 kg/m^3$)

V = wind speed (m/s).

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

$$P_w = \tfrac{1}{2} \times p \times C_e \times A \times V^3 \times 10^{-3} \ldots\ldots\ldots\ldots\ldots\ \ldots\ (3)$$

Where;

Ce stands for the wind turbine's greatest power extraction efficiency.

With more electrical devices linked to the generator.

3) Diesel Generator Consumption Model:

The intermittent output characteristics of renewable energy systems are combined with those of traditional power sources to produce a constant amount of power. Diesel generators (DG) provide a reliable source of power in a variety of HPSs. If the renewable energy source and battery alone are unable to meet the demand, the DG systems are intended to do so while also charging the battery energy storage system. Power energy balancing is necessary for optimal system performance because fuel consumption is inversely correlated with the amount of power supplied by the DG. Modeling shows that the diesel generator's fuel consumption (FG in 1/h) depends on DG output power in the following ways:

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

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 (1/kWh).

4) Battery Energy Storage System:

A battery is a crucial piece of electrical energy storage that allows for the best possible use of intermittent renewable resources. The lead-acid battery, which is frequently employed in HPS, is a sophisticated nonlinear component that regulates the system's operating states. 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 phenomena, such as gassing, double layer effect, self-discharge, heating loss, and diffusion, must be taken into account when modeling lead-acid batteries for real-time analysis of HPS. The battery's capacity for storage is listed as follows:

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

Where;

E_L = average daily load energy (kWh/day),

AD = daily autonomy of the battery;

DOD = battery depth of discharge,

While

μ_{inv} and μ_{batt} = inverter and battery efficiency respectively.

3.2. Methodology of Economic Analysis

The flowchart for the economic evaluation of HPSs is shown in Figure 3 below. The suggested hybrid systems' initial techno-economic feasibility analysis involved visiting rural areas and examining loads as well as weather data from various geographic locations. The investigations identified solar and wind energy systems as the two potential renewable energy sources that might be employed to satisfy the energy needs of rural areas. The modeling of the proposed hybrid systems then starts with the collection of data on the primary load, solar and wind potential, generation capacity, as well as typical market prices of the various parts that make up the hybrid system. This is not the case in hybrid systems because the various connected energy sources complement one another by utilizing their individual generators' load factors. In a one-source renewable system, the system tends to be oversized to accommodate the load demand with attendant results in high capital cost. The PV array, wind turbine, diesel generator, converter, and a number of batteries need to be sized appropriately in order to satisfy the load demand in this particular study.

In this study, the stand-alone diesel system, the hybrid PV-diesel system with and without battery, the hybrid wind-diesel system with and without battery, and the PV-wind-diesel system with and without battery were all examined. The levelized cost of energy (COE) and the renewable portion are two additional factors that are taken into account while determining the economic viability of each arrangement. Two key parameters for the consideration of environmentally friendly solutions are CO2 emission (tons/year) and diesel usage (1/year).

The HOMER program receives all of the input parameters in order to calculate the optimization outcomes for various system setups. The system configuration that offers the lowest COE is optimized to reduce the extra energy it produces. To make sure that the HPS components can fulfill the load expectations, the quantity of power they produce is compared to the yearly load demands. Additionally, the analysis of the standalone diesel system, PV-wind-diesel system with battery, and PV-diesel system with battery took into account the fluctuations in diesel costs.

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

3.3. Evaluation Performance Criteria

A wide range of system topologies using various combinations of energy sources that are both renewable and non-renewable are compared economically by HOMER [13]. Such comparisons must take into consideration the capital and running expenses of every source of energy in order to be fair. In this study, the performance of the hybrid system was assessed using three parameters: NPC, COE, and RE.

1) Net present cost (NPC):

Total net present cost (NPC), which is used in HOMER, is used to indicate the system life-cycle cost. The NPC includes fuel costs in addition to the initial capital cost, replacement cost, annual operating and maintenance cost. NPC is defined by equation (6).

$$C_{NPC} = TAC/\ CRF\ (iN) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ (6)$$

Where;

TAC = total annualized cost ($/year);

The capital recovery factor (CRF), which depends on the project duration (N) in years and the yearly real interest rate (i), is given in equation (7).

$$CRF\ (i,N) = i(1+i)^N / (1+i)^N - 1 \quad \ldots\ldots\ldots\ldots..(7)$$

2) Levelized cost of energy (COE):

The average price per kilowatt-hour of usable electrical energy generated by the system is known as the levelized cost of energy. The levelized cost of energy is calculated by HOMER using equation (8).

$$COE = TAC/\ E_{anloadserved} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ .(8)$$

Where,

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

3) Renewable fraction (RF):

The total electricity produced by renewable energy sources as a percentage of the total power produced by the overall hybrid system is known as the renewable fraction (RF). Since the load is required to use as much renewable energy as possible, RF is typically built to be as high as possible while taking into account its impact on NPC. The fraction that is renewable is obtained from;

$$RF(\%) = (1 - (\sum P_{diesel} / \sum P_{ren})) \times 100 \quad \ldots\ldots///\ldots\ldots..(9)$$

Where;

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

4. System Description and Implementation

All of the systems and tools used for the investigation are presented in this section. These consist of the load profile, simulation and optimization software, and an energy management supervisory controller.

4.1 Load Profile

In this study, the provision of energy in each of the chosen communities has taken into account domestic and infrastructure loads. In each area, it was assumed that there would be 50 dwellings, 1 primary health center, 1 public primary school, a salon, a provision store, a stationery store, a community hall, and a few other loads. From January to December, monthly estimates of the demands were made. Each month's daily load profile is shown in Figure 4. For the chosen sites, verified hourly load profiles are not available, hence typical daily load profiles were specified in order to synthesize the load data. The following traits apply to the load categories:

1) Domestic load:

The load for each family is based on four radios (10W), two ceiling fans (30W each), one television (80W), and four energy-efficient compact fluorescent bulbs (20W each). The daily load demand is roughly 108 kWh.

2). Social Infrastructure:

Demand for the primary health center, public elementary school, community center, and stores are included in this. The daily load demand is roughly 15 kWh.

4.2 Solar Radiation

The amount of direct and diffuse solar radiation in a particular area has a significant impact on the PV array's power production. The amount of radiation that reaches the surface of the earth relies on the amount of cloud cover or sky clarity, which in turn varies on the time of year. One of the renewable energy sources that is easily accessible in Nigeria is solar energy. Nigeria receives approximately 5.75 kwh/m2/day of solar energy on average, with 4-7.5 hours of sunshine per day. According to the Solar Electricity Handbook global satellite database (www.solarelectricityhandbook.com/solar-irradiance.html) [14] and using the solar panel direction of East South East (67.5'), Table 3 displays the solar irradiation for each chosen site. The latitude and longitude of each of the six locations were used to determine the sun radiation data for each site, which was then measured using a precision pyrometer and previously displayed in Table 1.

When compared to the dry season, there is less solar radiation and intensity for all of the settlements taken into account. The country's southern portion demonstrates the low irradiation potential needed for significant power generation. In general, it is discovered that all of the locations under consideration are substantially clouded between July and August (the height of the rainy season), which causes a notable decline in the world's solar potential as a result of the heavy cloud cover.

The PV panel costs based on the size of the PV panel type, the percentage of capital expenses included for installation and BOS (Balance of System) parts, and added fixed costs accounting for installation and BOS parts, respectively, make up the initial costs of the PV array. Monthly fixed costs and annual costs expressed as a percentage of capital costs can be used to represent the operation and maintenance of PV arrays. These fees can go towards a maintenance worker's inspection of the system. Assuming that PV array replacement events happen every 20 years, there won't be any replacement costs for projects with a lifespan of 20 years or fewer.

4.3 Wind speed

When wind blows through a wind turbine, electrical energy can be produced from wind energy. By whirling the turbine blade at the specified wind speed, the kinetic energy of the wind is transformed into mechanical power, which generates electricity through the shaft attached to the alternator. Using an anemometer at 10 meters above sea level, the Time and Date Weather global database (www.timeanddate.com/weather/nigeria) [15] was used to collect the monthly average wind speed data for an average of ten (10) years. Table 4 displays the annual average wind speed for each village. The spot that was chosen has winds that blow between 2.9 and 6.9 m/s. The geography, water bodies, and vegetation cover of the earth all affect how the wind patterns alter. The peak wind speed occurs at 15.00 hours, according to observations of the wind likelihood and average monthly speed over the course of a year. Figure 5 depicts the Iwofe village's typical wind speed.

Similar to how the PV array's costing variables (initial cost, operating cost, and replacement cost) were developed. Maintenance and replacement costs are included in wind turbine operating costs. Depending on the application, kind of maintenance, and size of the wind turbine, maintenance expenses can vary. Since the expected lifespan of a wind turbine is frequently anticipated to be greater than 20 years, in many life cycle costing scenarios, there won't be any wind turbine replacements.

4.4 Diesel

The current exchange rate in Nigeria is 356 naira to 1 dollar (at the time of this research), making the cost of diesel \$0.56 a liter. This cost varies in accordance with the world market. In order to examine its impact on the overall system cost and environment, the price of diesel is assumed to stay constant in this study.

The starting costs of a diesel generator are its cost in relation to its size, the percentage of capital costs added for installation and BOS parts for its kind, and the equivalent extra fixed costs. Fuel costs, maintenance, repair, and replacement expenses are included in the diesel generator running costs. Every time the gasoline storage tanks are refilled, fuel costs are incurred. Halfway through the diesel's lifetime, an overhaul is presumed. After a given number of hours of operation, diesel generators need to be replaced. The period of time until a mechanical overhaul is no longer cost-effective (i.e. when overhaul costs are greater than 60% of replacement costs) is the effective lifetime of a diesel generator The standard and frequency of maintenance, average capacity factor, and quantity of starts-ups are all factors that affect lifetime. A machine that is water-cooled and can maintain a lower operating temperature will likely last longer than one that uses air cooling.

4.5 Components Data

The suggested hybrid systems include diesel generators, wind turbines, solar panels, and other system parts including batteries and converters. To maximize system output and account for the unpredictability of variation in RE sources from one zone to the next, the PV panel, wind turbine, and diesel turbine generator worked together. When renewable resources are sufficiently investigated, hybrid system maintenance and replacement costs can be decreased. A hybrid system often has a high initial capital cost; as a result, long-lasting, dependable, and affordable solutions are required to meet the needs of the entire project life.

The capital cost and replacement cost of a 1W PV array were taken as \$3 and \$2.0, respectively (Price from eBay shop), and are expressed below as assumptions for component pricing and sizing as adopted in the recommended hybrid system. A 20-year lifespan for PV arrays was assumed. The de-rating factor, which takes into account losses from temperature effects and dirt on the surface of PV modules, was considered to be 90%, while the ground reflection of the modules was assumed to be 20%. To determine the best PV array size for each hamlet, various array sizes were taken into account.

4.6 Dispatch strategy and Constraints

A dispatch strategy is a collection of guidelines that manages how the energy storage device and a number of associated generators operate. In the HOMER software, there are two different types of dispatch strategies: cycle charging (CC) and load following (LF). The CC approach uses the generator to supply the load at its full rated capacity while also charging the battery, as opposed to the LF strategy, which automatically runs the diesel generator to serve the load alone without charging the battery storage system. The best dispatch approach for the proposed system will depend on a number of factors, including the battery bank size, fuel price, operating and maintenance costs for diesel generators, and renewable energy Both tactics were taken into account in the suggested system using HOMER. restrictions are prerequisites that systems must meet; if not, HOMER will disregard any systems that do not satisfy the specified restrictions. The maximum renewable portion of the proposed system ranges from 0% to 100%, and excess energy is dependent on local resource availability. The maximum yearly capacity shortage was set at 2%.

Users can enter any amount of PV size (in kW) in HOMER to account for the worst-case situation (i.e., a time of low solar irradiation). The site's power needs and the amount of available space for installing the panels may both affect the PV's size. However, in this study, the hybrid system's complete PV module count was sized for each site to account for the worst-case scenarios throughout the year. Although the amount of extra energy generated is more noticeable during the months with high solar radiation due to the larger size of the PV choice, the more PV capacity, the more electricity the PV modules produce during the day.

5. Data Presentation, Results Analysis and Discussion

In order to assess operational characteristics such as annual electricity production, annual load served, excess electricity, renewable fraction, and other factors, the software used in this study (HOMER) performs an hourly time series simulation for every possible system configuration on an annual basis. The viability of the system was assessed using both the diesel load generator and renewable energy sources. In order to achieve the load demand at the lowest cost (NPC), HOMER looked for the best system configuration and component sizes. It then delivers the simulation findings in terms of the best systems and sensitivity analysis.

The tilt sensitivity variables selected are used to categorize the best outcomes. The system design is displayed in Table 6 along with the kW ratings for the converter, diesel generator, wind turbine, and array. The system architecture also specifies the amount of batteries needed for energy storage. In this work, the typical stand-alone diesel generator is used as the base case simulation because it is being used in the majority of Nigeria's rural areas. The choice was taken to enable a comparison of the overall savings that can be realized by incorporating a renewable energy source into the system design and execution of a hybrid power system (i.e., comparing the cost and emissions of DC with the recommended hybrid In comparison to the base case simulation with respect to NPC, the PV/diesel/battery/converter configuration is judged to be the best in Ikpa Road, Abraka, Edibe Edibe, and Okada, and the Wind/diesel/battery/converter configuration is judged to be the best in Iwofe and Wilberforce island. RF, carbon emissions, and diesel consumption for the diesel price ($0.56/1) are also evaluated.

5.1 Total NPC Calculations

For a diesel price of $0.56/ 1, the NPC of every practicable system configuration taken into account for the implementation of hybrid power systems at the chosen sites is shown. On the assumption that the system will last 20 years, NPC is estimated for the entire system. As shown in Table 5, the system configuration consists of the following components: Wind/ Diesel/ Battery/ Converter, PV/ Wind/ Diesel/ Battery/ Converter, Diesel/ Battery/ Converter, PV/ Diesel/ Battery/ Converter, PV/ Wind/ Diesel/ Battery/ Converter, and Diesel Standalone.

When comparing the average total NPC of each configuration in Table 5, it can be shown from the NPC study that the stand-alone PV/Wind/Diesel/Battery/Converter system has the lowest NPC of all the locations that were analyzed. In this study, system configurations for hybrid PV/Wind/Diesel/Battery/Converter will be compared primarily. Due to the often low wind speeds at the sites, the wind system is not the ideal choice. The graphical representations of NPC and COE for PV/Wind/Diesel/Battery systems across all sites are shown in Figs. 13 and 14. $1 N356 was used throughout the entire NPC computation, where $ stood for US dollars and N for Naira, the currency of Nigeria.

Wilberforce Island, which is located in the tropical monsoon climate zone, has the lowest "NPC." The NPC is $464240 at $0.56/L, and the COE is $1.03/kWh. The outcome demonstrates the direct correlation between NPC and component resource levels (solar radiation and wind speed), The NPC value will be lower at sites with stronger sun radiation, and The NPC value will be lower at a spot where the wind speed is higher. This is due to the fact that high irradiation will allow the PV system to supply the load for a longer length of time, lowering the number of hours the diesel generator must run. As a result, the consumption and cost of fuel will be reduced, directly affecting low NPC.

Iwofe, which has a tropical wet climate and a value of $464248, is next to Wilberforce Island and is followed by Abraka, which has a value of $507588NPC. The average solar radiation and wind speed between these places differ very little, it is discovered. Out of the six sites taken into account in the simulation, Okada, which symbolises the tropical environment, displayed the highest NPC. This can be attributed to the site's lower average daily global wind speed than that of Wilberforce Island and Iwofe. Okada's total NPC is $519876; by comparing it to the basic case NPC (i.e., using a diesel generator alone), $347,050 can be saved.

5.2 System Architecture

Based on the $0.56/L diesel price taken into consideration, Table 6 shows the number of components chosen for the most practical design (PV/Wind/Diesel/Battery) in each state in the south of Nigeria. In order to determine the optimal amount of system components, HOMER took into account a variety of factors, including the load profile, world wind speed, global sun irradiation, and fuel pricing. The process of component optimization places a high priority on the hybrid system's ability to continuously satisfy load needs. This is done to prevent large PV systems and wind turbines as well as to ensure minimal diesel usage. The size of the battery component takes installation space into account as well.

Out of all the sites taken into consideration, Wilberforce Island produced the system architecture with the smallest component size. 64 batteries, a 10.5 kW converter, a 17 kW generator, and a 0.59 kW solar panel make up the system architecture. The simulation revealed that with the exception of Edibe Edibe, the majority of the sites under consideration indicated a rise in the size of their PV panels and battery banks. This justifies the additional expenditures of putting in a bigger PV array and boosting the system's storage capacity in order to reduce the amount of time the generator runs and keep the NPC as low as necessary.

5.3 RF Calculations

For each site taken into account in the simulation, the renewable fraction varies according to the system topologies. The RF for each site in the simulation is noticeably high for the sensitivity scenario of $0.56/1, as can be seen in (Fig. 15). Iwofe, Wilberforce, and Edibe Edibe suffer high RF values; their respective values are 0.29, 0.26, and 0.22 at $0.56/L. The Okada sensitivity scenario of $0.56/I has the lowest RF of 0.19. For the same $0.56/1 price of diesel, Ikpa Road and Abraka also enjoy relatively low RF of 0.20 and 0.21, respectively.

5.4 Carbon Emissions and Diesel Consumption

The annual fuel consumption of the diesel generator in liters directly relates to annual CO2 emissions. According to a base case simulation at a diesel price of $0.56/1, Fig. 15 compares the total quantity of diesel utilized annually by PV/diesel/battery configurations for each location.

CO2 Iwofe site utilized the least amount of diesel per year (9713L at a diesel price of $0.56/I), whereas the Okada site consumed the most. Emissions in kg/yr for the sensitivity scenarios at each site are indicated.

The hybrid renewable energy system configuration offers a significant reduction in CO2 emissions when Figs. 16 and 23 are compared, as the lower the fuel consumption, the lower the CO2 emissions (diesel generator system). The city with the lowest CO2 emissions is Iwofe (25424.88 kg/yr). Wilber Force Island came next (26770.56 kg/year). Okada recorded the highest CO2 emissions value, which is 28716.36 kg/yr for the sensitivity case of $0.56 /1.

5.5. 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. The total Ac primary load for all the locations is the same having 45092kWh/yr consumption.

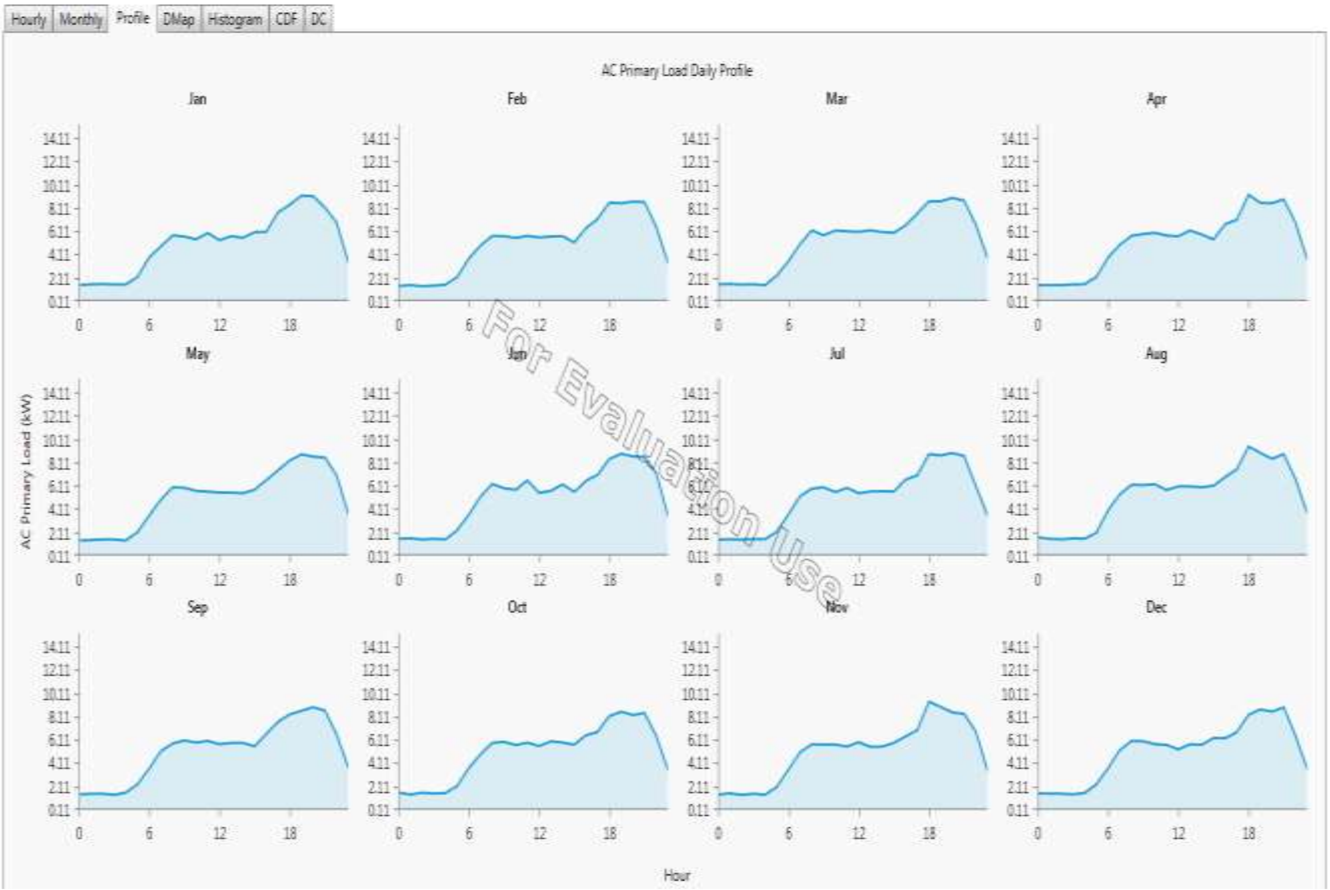


Figure 4: Monthly AC Primary Load Profile

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) Refrigerator Television Ceiling fan **Total**	6 1 1 2	20 600 80 30	10 16 6 12	1200 9600 480 720 **12000**
• Public primary school Lighting (CFL) Ceiling fan **Total**	7 1	20 30	4 6	560 180 **740**
• Community hall and shops Lighting Ceiling fan Television Total load Miscellaneous load **Total load consumption**	10 4 1	20 30 80 80	5 7 6 6	1000 840 480 **2320** 480 **123540**

TABLE III
SOLAR IRRADIATION DATA FOR THE SIX VILLAGES (KWH/M^2/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**

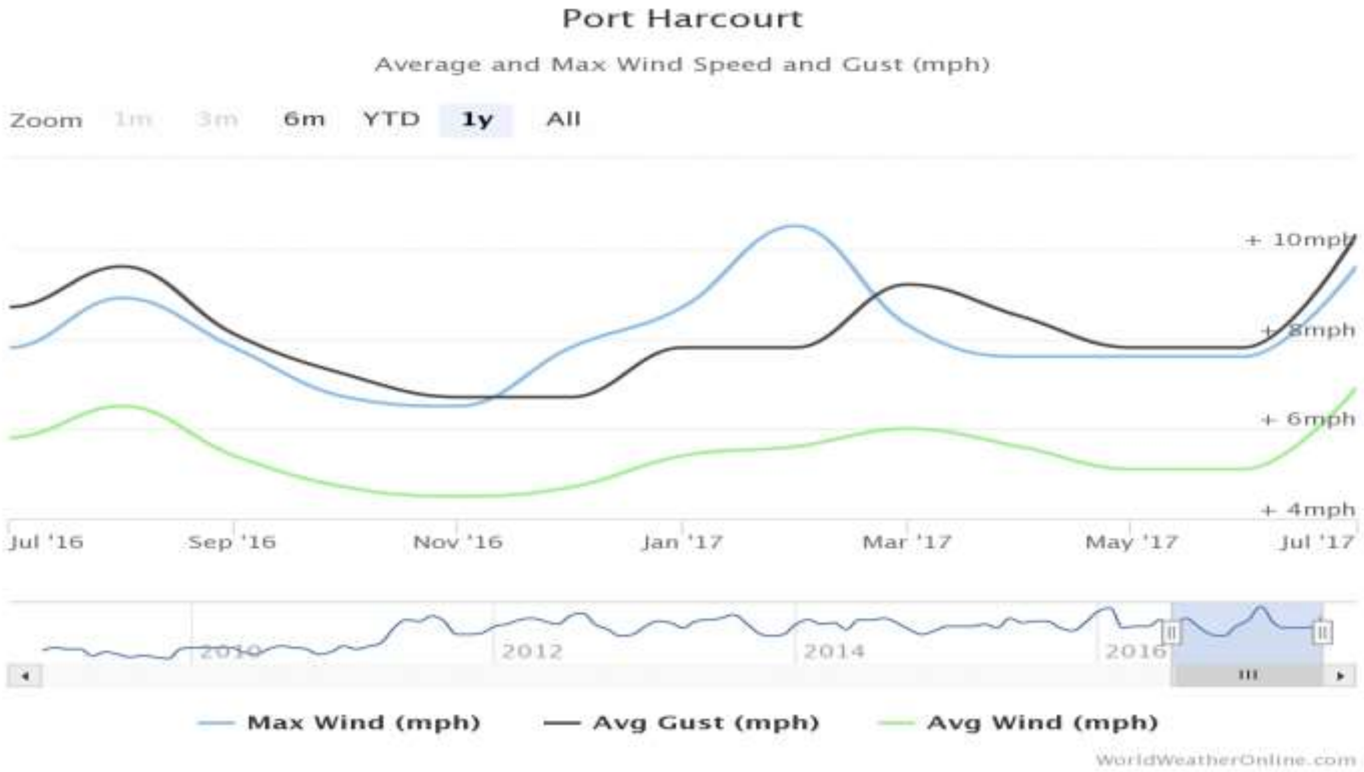


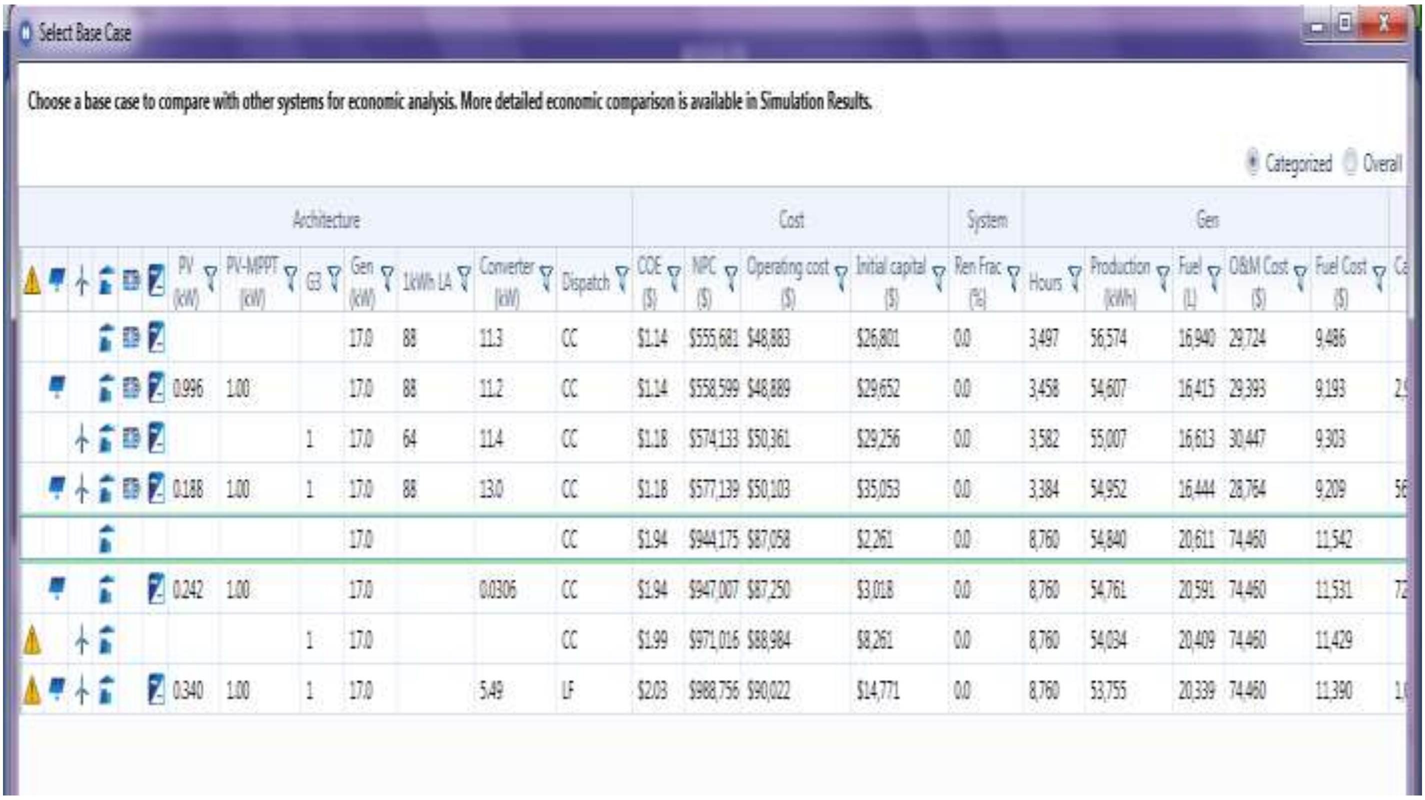
Figure 5: Wind Speed Data for Iwofe Village, Port Harcourt.

TABLE IV
WIND SPEED DATA FOR THE SIX VILLAGES

Month	**Villages**					
	Iwofe	**Wilberforce Island**	**Ikpa Road**	**Okada**	**EdibeEdibe**	**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	-



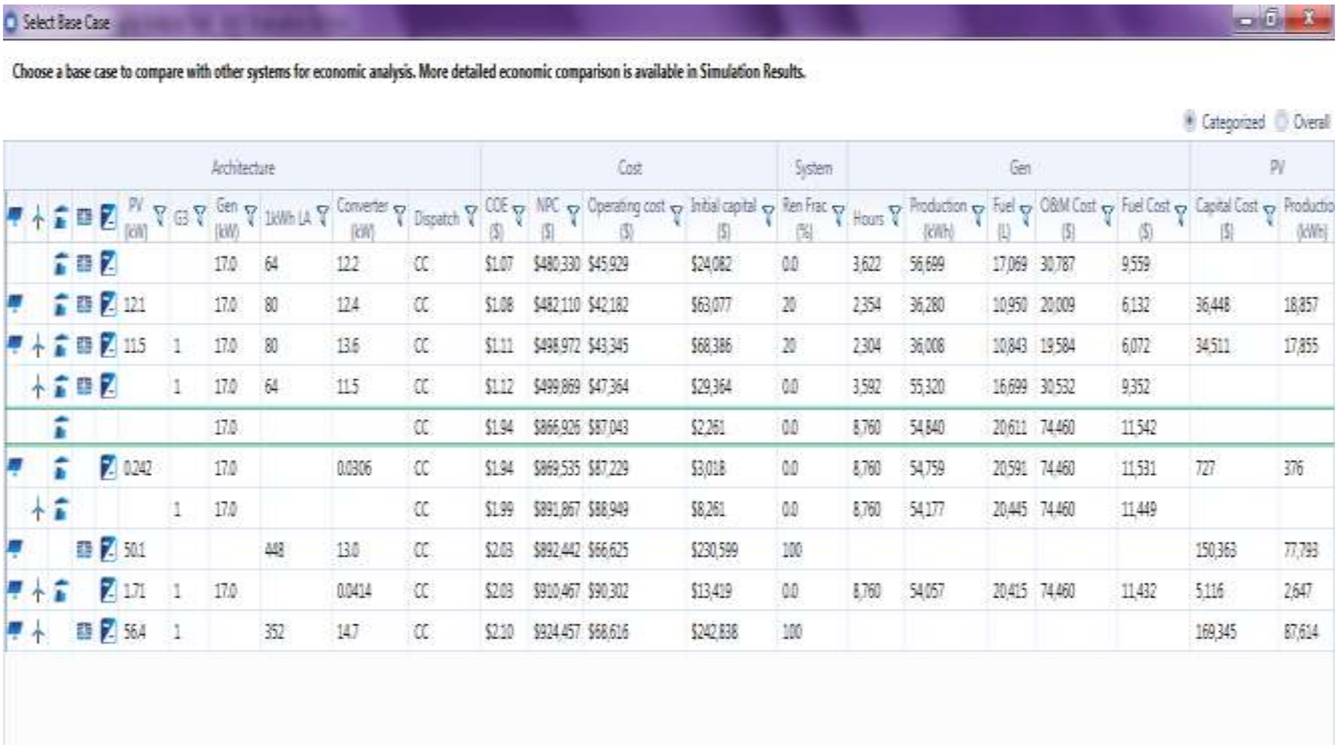
Select Base Case

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)	PV-MPPT (kW)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)
			17.0	88	11.3	CC	$1.14	$555,681	$48,883	$26,801	0.0	3,497	56,574	16,940	29,724	9,486
0.996	1.00		17.0	88	11.2	CC	$1.14	$558,599	$48,889	$29,652	0.0	3,458	54,607	16,415	29,393	9,193
		1	17.0	64	11.4	CC	$1.18	$574,133	$50,361	$29,256	0.0	3,582	55,007	16,613	30,447	9,303
0.188	1.00	1	17.0	88	13.0	CC	$1.18	$577,139	$50,103	$35,053	0.0	3,384	54,952	16,444	28,764	9,209
			17.0			CC	$1.94	$944,175	$87,058	$2,261	0.0	8,760	54,840	20,611	74,460	11,542
0.242	1.00		17.0		0.0306	CC	$1.94	$947,007	$87,250	$3,018	0.0	8,760	54,761	20,591	74,460	11,531
		1	17.0			CC	$1.99	$971,016	$88,984	$8,261	0.0	8,760	54,034	20,409	74,460	11,429
0.340	1.00	1	17.0		5.49	LF	$2.03	$988,756	$90,022	$14,771	0.0	8,760	53,755	20,339	74,460	11,390

Figure 6: NPC for Diesel Price of $0.56/1 for System Configuration for Iwofe



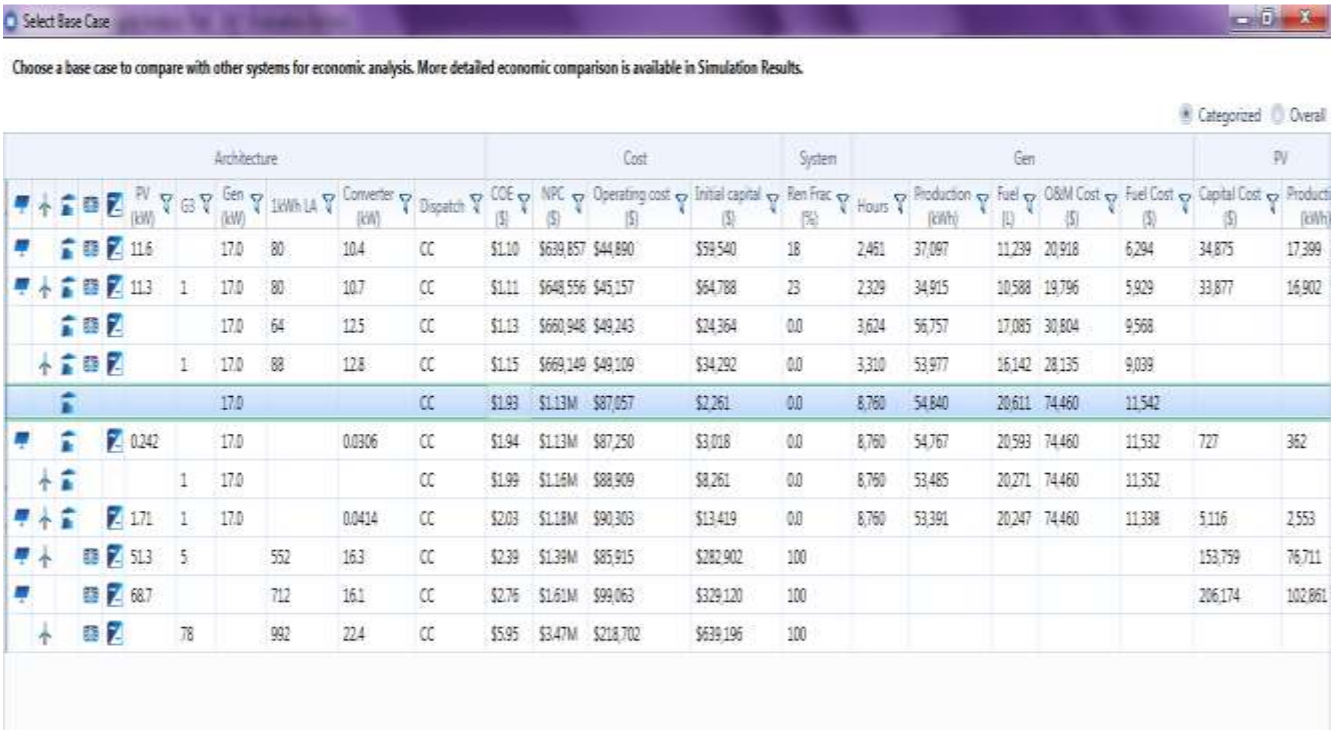
Select Base Case

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)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Productio (kWh)
		●	●	●			17.0	64	12.2	CC	$1.07	$480,330	$45,929	$24,082	0.0	3,622	56,699	17,069	30,787	9,559		
●		●	●	●	12.1		17.0	80	12.4	CC	$1.08	$482,110	$42,182	$63,077	20	2,354	36,280	10,950	20,009	6,132	36,448	18,857
●	●	●	●	●	11.5	1	17.0	80	13.6	CC	$1.11	$498,972	$43,345	$68,386	20	2,304	36,008	10,843	19,584	6,072	34,511	17,855
	●	●	●	●		1	17.0	64	11.5	CC	$1.12	$499,869	$47,364	$29,364	0.0	3,592	55,320	16,699	30,532	9,352		
		●					17.0			CC	$1.94	$866,926	$87,043	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
●		●		●	0.242		17.0		0.0306	CC	$1.94	$869,535	$87,229	$3,018	0.0	8,760	54,759	20,591	74,460	11,531	727	376
	●	●				1	17.0			CC	$1.99	$891,867	$88,949	$8,261	0.0	8,760	54,177	20,445	74,460	11,449		
●			●	●	50.1			448	13.0	CC	$2.03	$892,442	$66,625	$230,599	100						150,363	77,793
●	●	●		●	1.71	1	17.0		0.0414	CC	$2.03	$910,467	$90,302	$13,419	0.0	8,760	54,057	20,415	74,460	11,432	5,116	2,647
●	●		●	●	56.4	1		352	14.7	CC	$2.10	$924,457	$68,616	$242,838	100						169,345	87,614

Figure 7: NPC for Diesel Price of $0.56/1 for System Configuration for Wilber force Island



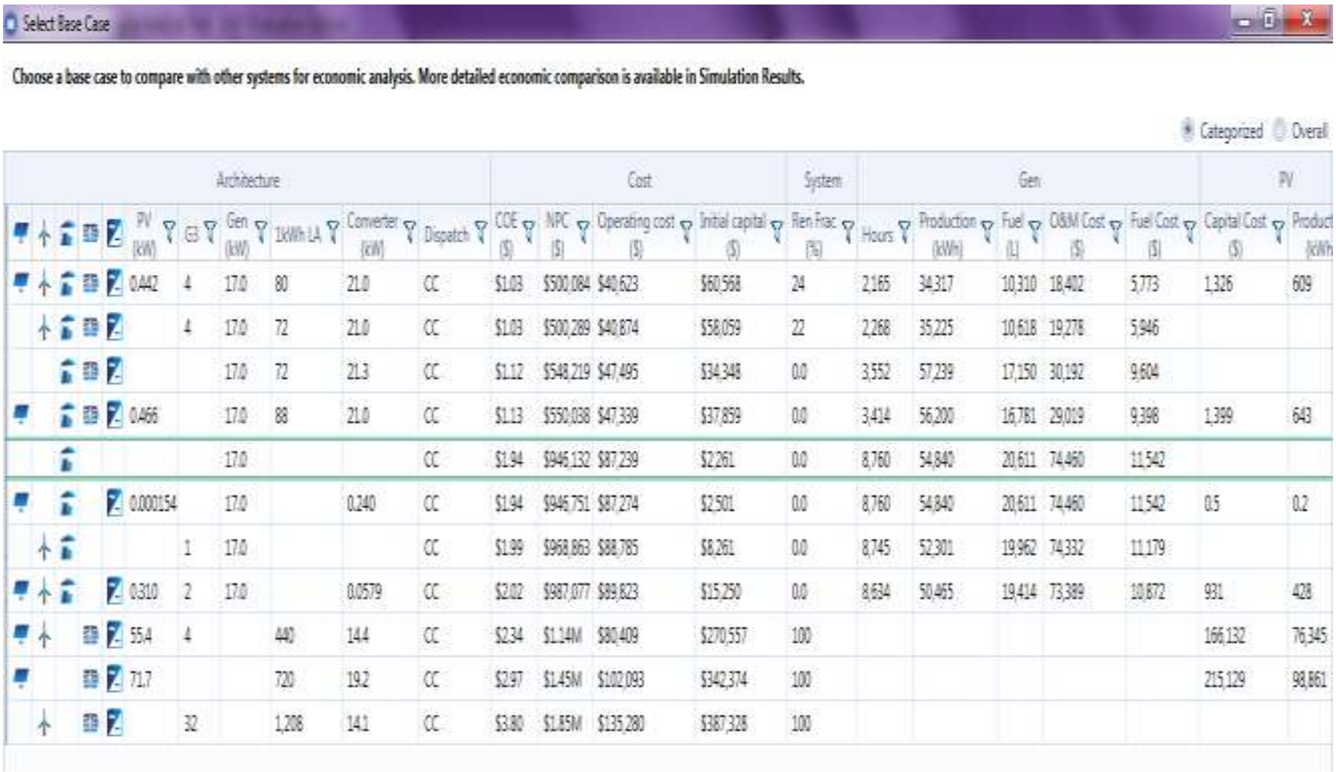
Select Base Case

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)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Producti (kWh)
●		●	●	●	11.6		17.0	80	10.4	CC	$1.10	$639,857	$44,890	$59,540	18	2,461	37,097	11,239	20,918	6,294	34,875	17,399
●	●	●	●	●	11.3	1	17.0	80	10.7	CC	$1.11	$648,556	$45,157	$64,788	23	2,329	34,915	10,588	19,796	5,929	33,877	16,902
		●	●	●			17.0	64	12.5	CC	$1.13	$660,948	$49,243	$24,364	0.0	3,624	56,757	17,085	30,804	9,568		
	●	●	●	●		1	17.0	88	12.8	CC	$1.15	$669,149	$49,109	$34,292	0.0	3,310	53,977	16,142	28,135	9,039		
		●					17.0			CC	$1.93	$1.13M	$87,057	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
●		●		●	0.242		17.0		0.0306	CC	$1.94	$1.13M	$87,250	$3,018	0.0	8,760	54,767	20,593	74,460	11,532	727	362
	●	●				1	17.0			CC	$1.99	$1.16M	$88,909	$8,261	0.0	8,760	53,485	20,271	74,460	11,352		
●	●	●		●	1.71	1	17.0		0.0414	CC	$2.03	$1.18M	$90,303	$13,419	0.0	8,760	53,391	20,247	74,460	11,338	5,116	2,553
●	●		●	●	51.3	5		552	16.3	CC	$2.39	$1.39M	$85,915	$282,902	100						153,759	76,711
●			●	●	68.7			712	16.1	CC	$2.76	$1.61M	$99,063	$329,120	100						206,174	102,861
	●		●	●		78		992	22.4	CC	$5.95	$3.47M	$218,702	$639,196	100							

Figure 8: NPC for Diesel Price of $0.56/1 for System Configuration for Ikpa Road

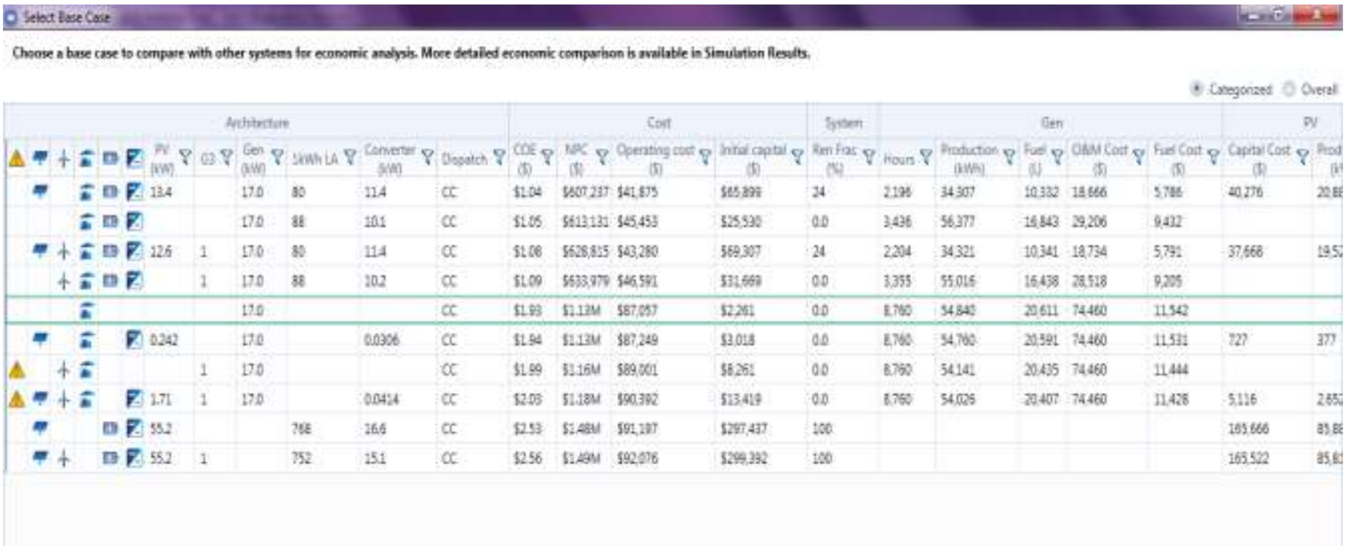


Choose a base case to compare with other systems for economic analysis. More detailed economic comparison is available in Simulation Results.

● Categorized ○ Overall

Architecture						Cost				System	Gen						PV	
PV (kW)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Product (kWh
0.442	4	17.0	80	21.0	CC	$1.03	$500,084	$40,623	$60,568	24	2,165	34,317	10,310	18,402	5,773	1,326	609
	4	17.0	72	21.0	CC	$1.03	$500,289	$40,874	$58,059	22	2,268	35,225	10,618	19,278	5,946		
		17.0	72	21.3	CC	$1.12	$548,219	$47,495	$34,348	0.0	3,552	57,239	17,150	30,192	9,604		
0.466		17.0	88	21.0	CC	$1.13	$550,038	$47,339	$37,859	0.0	3,414	56,200	16,781	29,019	9,398	1,399	643
		17.0			CC	$1.94	$946,132	$87,239	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.000154		17.0		0.240	CC	$1.94	$946,751	$87,274	$2,501	0.0	8,760	54,840	20,611	74,460	11,542	0.5	0.2
	1	17.0			CC	$1.99	$968,863	$88,785	$8,261	0.0	8,745	52,301	19,962	74,332	11,179		
0.310	2	17.0		0.0579	CC	$2.02	$987,077	$89,823	$15,250	0.0	8,634	50,465	19,414	73,389	10,872	931	428
55.4	4		440	14.4	CC	$2.34	$1.14M	$80,409	$270,557	100						166,132	76,345
71.7			720	19.2	CC	$2.97	$1.45M	$102,093	$342,374	100						215,129	98,861
	32		1,208	14.1	CC	$3.80	$1.85M	$135,280	$387,328	100							

Figure 9: NPC for Diesel Price of $0.56/1 for System Configuration for Okada

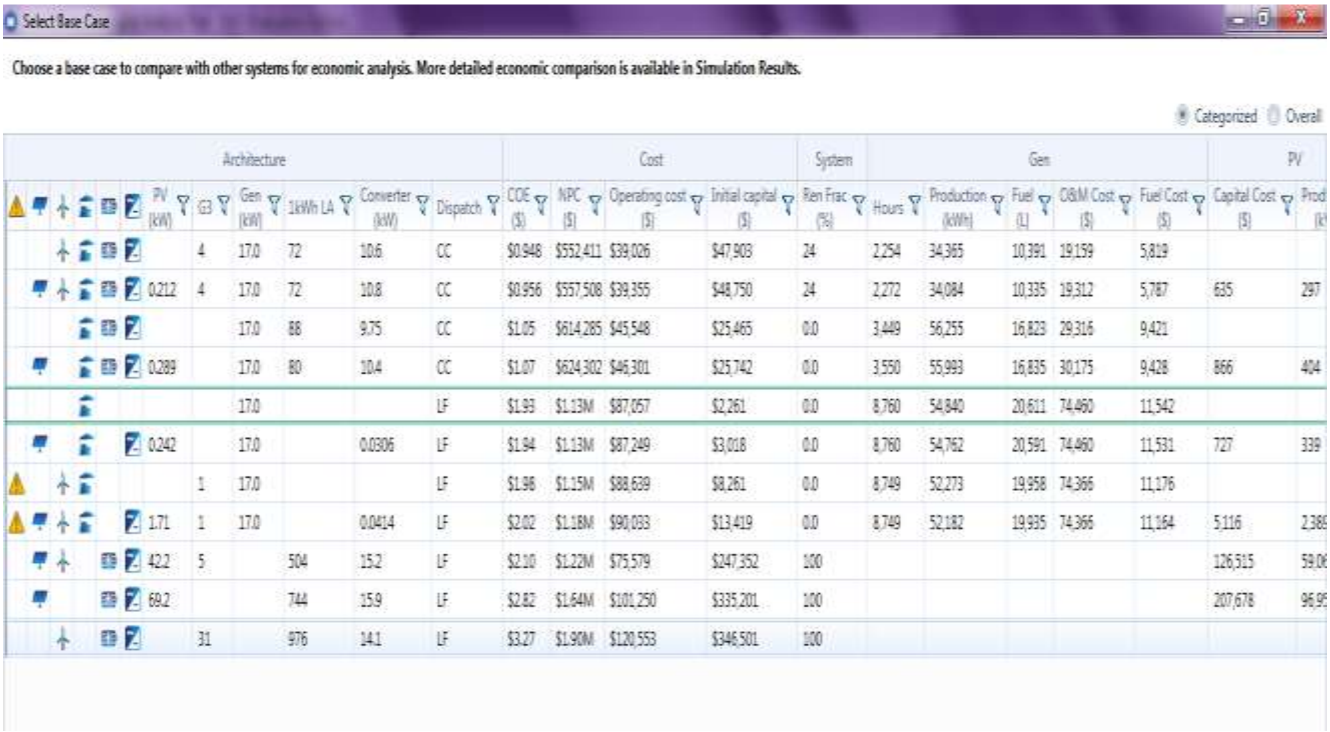


Choose a base case to compare with other systems for economic analysis. More detailed economic comparison is available in Simulation Results.

● Categorized ○ Overall

Architecture						Cost				System	Gen						PV	
PV (kW)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Prod (k
13.4		17.0	80	11.4	CC	$1.04	$607,237	$41,875	$65,899	24	2,196	34,307	10,332	18,666	5,786	40,276	20,8
		17.0	88	10.1	CC	$1.05	$613,131	$45,453	$25,530	0.0	3,436	56,377	16,843	29,206	9,432		
12.6	1	17.0	80	11.4	CC	$1.08	$628,815	$43,280	$69,307	24	2,204	34,321	10,341	18,734	5,791	37,668	19,5
	1	17.0	88	10.2	CC	$1.09	$633,979	$46,591	$31,669	0.0	3,355	55,016	16,438	28,518	9,205		
		17.0			CC	$1.93	$1.13M	$87,057	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
0.242		17.0		0.0306	CC	$1.94	$1.13M	$87,249	$3,018	0.0	8,760	54,760	20,591	74,460	11,531	727	377
	1	17.0			CC	$1.99	$1.16M	$89,001	$8,261	0.0	8,760	54,141	20,435	74,460	11,444		
1.71	1	17.0		0.0414	CC	$2.03	$1.18M	$90,392	$13,419	0.0	8,760	54,026	20,407	74,460	11,428	5,116	2,65
55.2			768	16.6	CC	$2.53	$1.48M	$91,187	$297,437	100						165,666	85,8
55.2	1		752	15.1	CC	$2.56	$1.49M	$92,076	$299,392	100						165,522	85,8

Figure 10: NPC for diesel price of $0.56/1 for System configuration for Edibe Edibe



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)	G3	Gen (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($)	Fuel Cost ($)	Capital Cost ($)	Prod (k
		●	●	●	●		4	17.0	72	10.6	CC	$0.948	$552,411	$39,026	$47,903	24	2,254	34,365	10,391	19,159	5,819		
	●	●	●	●	●	0.212	4	17.0	72	10.8	CC	$0.956	$557,508	$39,355	$48,750	24	2,272	34,084	10,335	19,312	5,787	635	297
			●	●	●			17.0	88	9.75	CC	$1.05	$614,285	$45,548	$25,465	0.0	3,449	56,255	16,823	29,316	9,421		
	●		●	●	●	0.289		17.0	80	10.4	CC	$1.07	$624,302	$46,301	$25,742	0.0	3,550	55,993	16,835	30,175	9,428	866	404
			●					17.0			LF	$1.93	$1.13M	$87,057	$2,261	0.0	8,760	54,840	20,611	74,460	11,542		
	●		●		●	0.242		17.0		0.0306	LF	$1.94	$1.13M	$87,249	$3,018	0.0	8,760	54,762	20,591	74,460	11,531	727	339
⚠		●	●				1	17.0			LF	$1.96	$1.15M	$88,639	$8,261	0.0	8,749	52,273	19,958	74,366	11,176		
⚠	●	●	●		●	1.71	1	17.0		0.0414	LF	$2.02	$1.18M	$90,033	$13,419	0.0	8,749	52,182	19,935	74,366	11,164	5,116	2,38
	●	●		●	●	42.2	5		504	15.2	LF	$2.10	$1.22M	$75,579	$247,352	100						126,515	59,0
	●			●	●	69.2			744	15.9	LF	$2.82	$1.64M	$101,250	$335,201	100						207,678	96,9
		●		●	●		31		976	14.1	LF	$3.27	$1.90M	$120,553	$346,501	100							

Figure 11: NPC for Diesel Price of $0.56/1 for System Configuration for Abraka

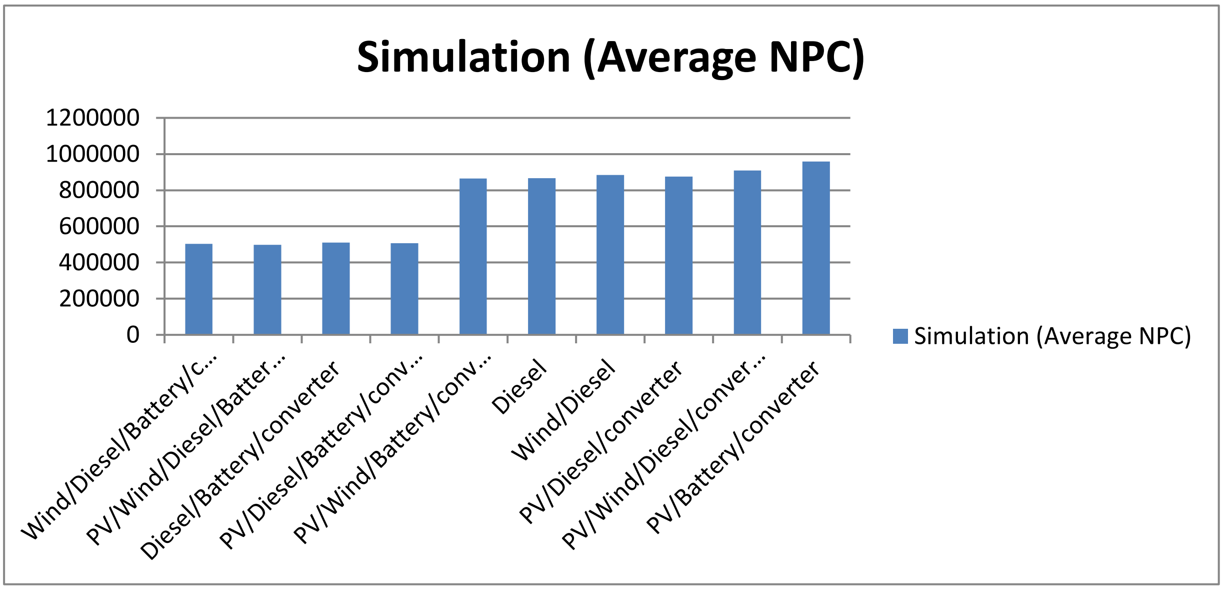


Figure 12: NPC for Diesel Price of $0.56/1 for 10 System Configurations

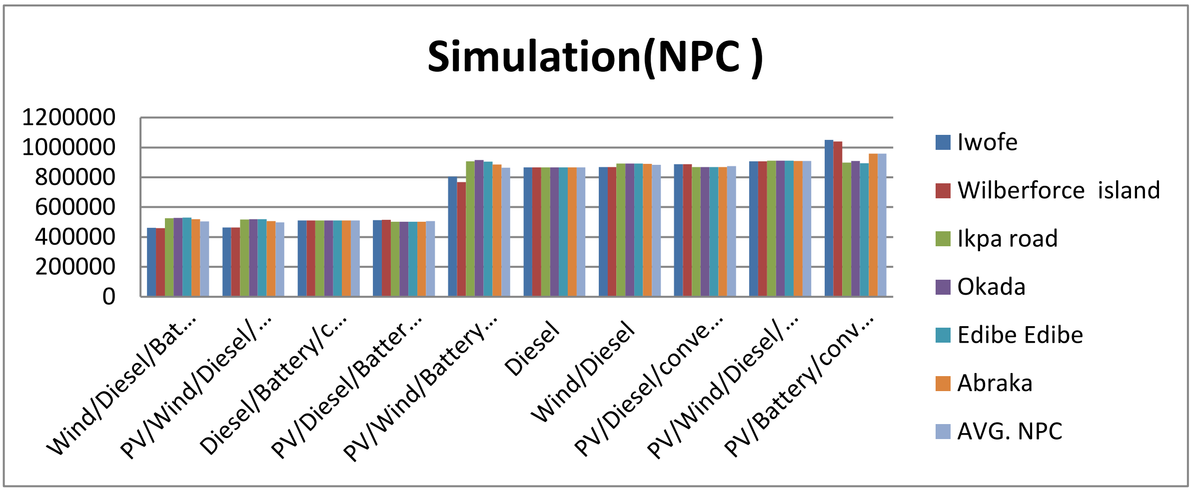
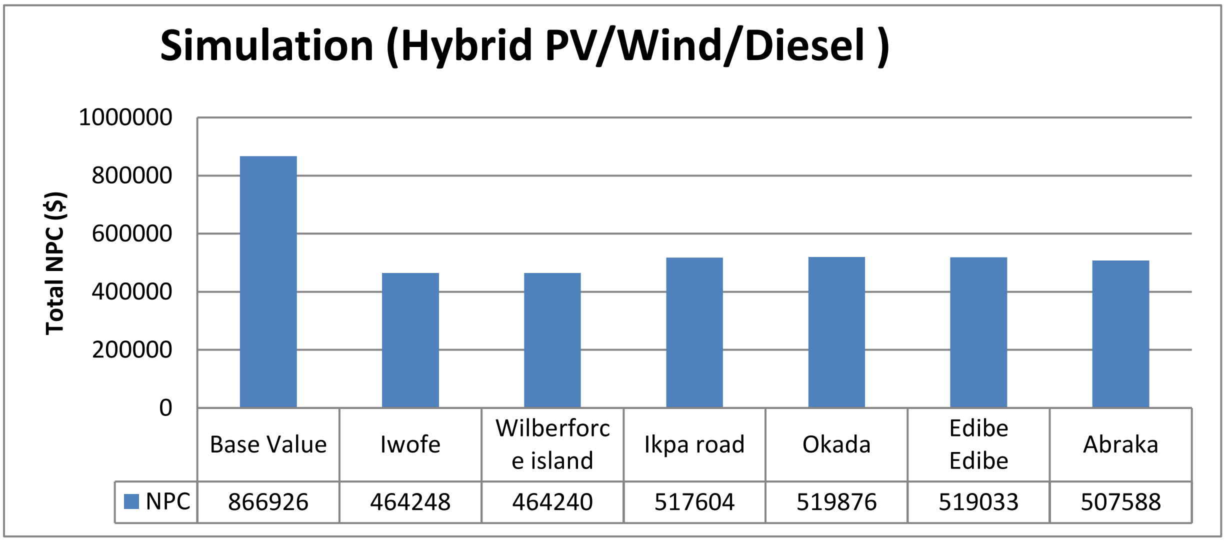


Figure 13: NPC for All Location and 10 System Configurations



	Base Value	Iwofe	Wilberforce island	Ikpa road	Okada	Edibe Edibe	Abraka
■ NPC	866926	464248	464240	517604	519876	519033	507588

Figure 14: Graphical Representation of NPC for Hybrid PV/Wind/Diesel/Battery System

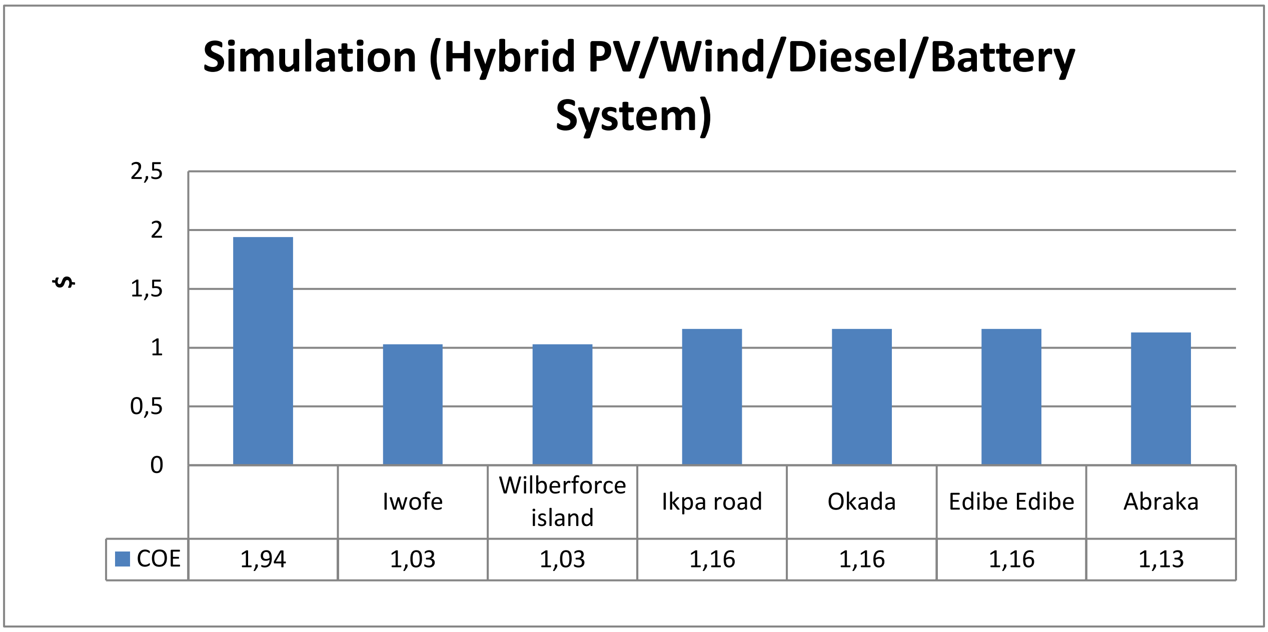


Figure 15: Graphical Representation of COE for Hybrid Power System

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

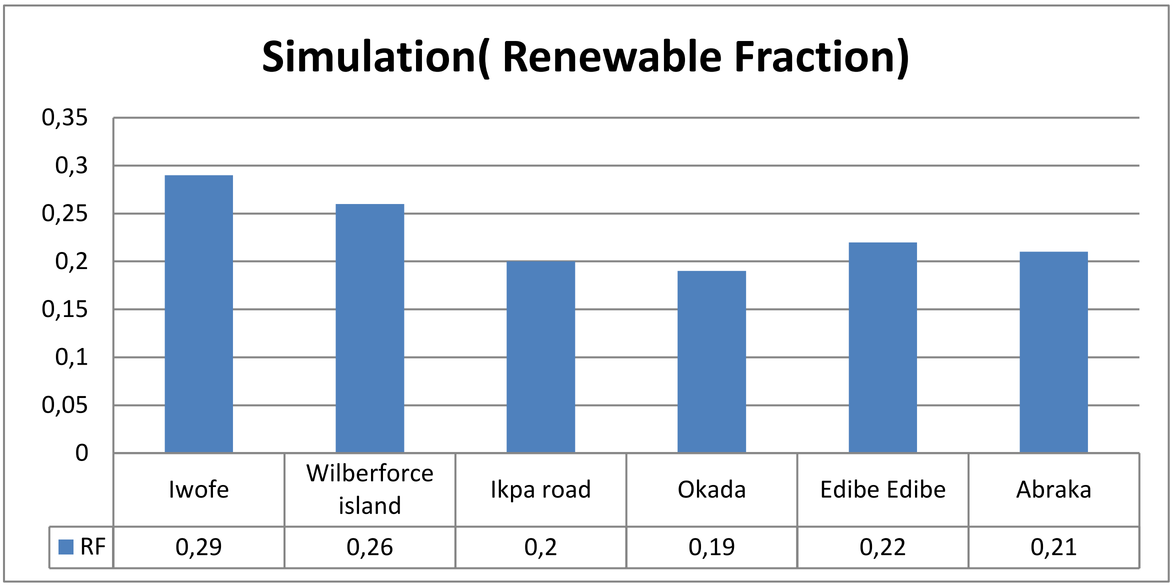


Figure 16: RF for Diesel Price of $0.56

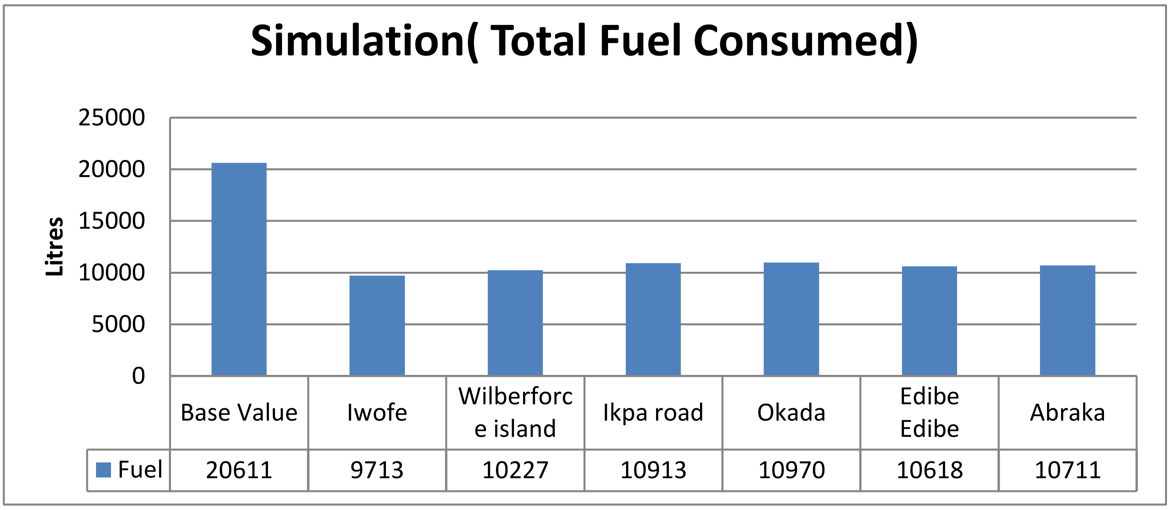
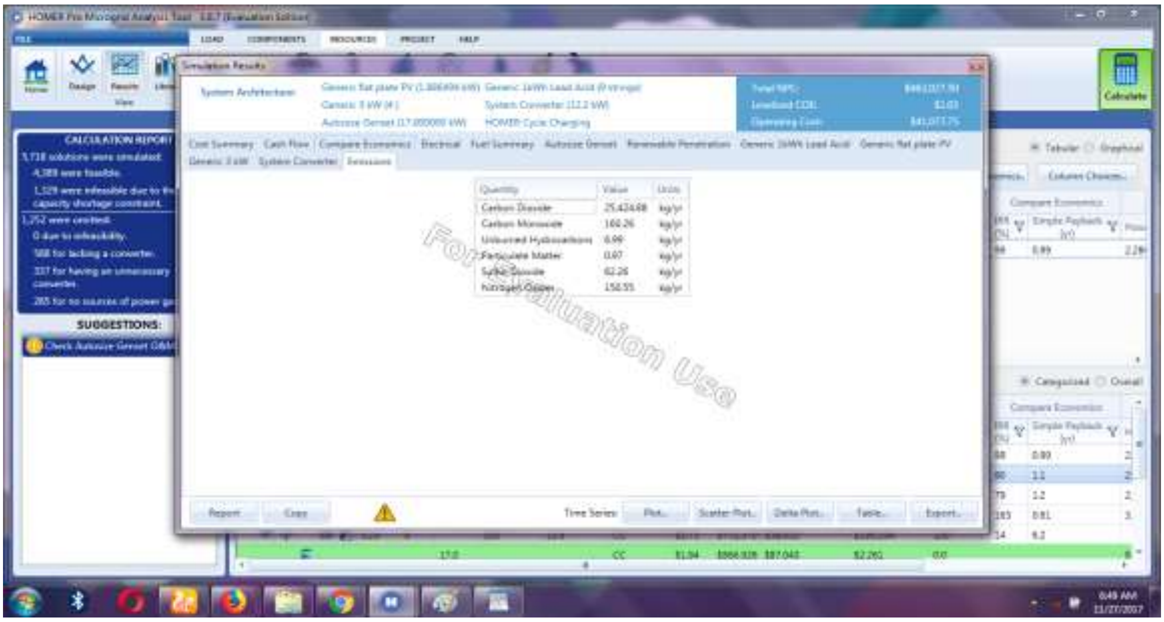
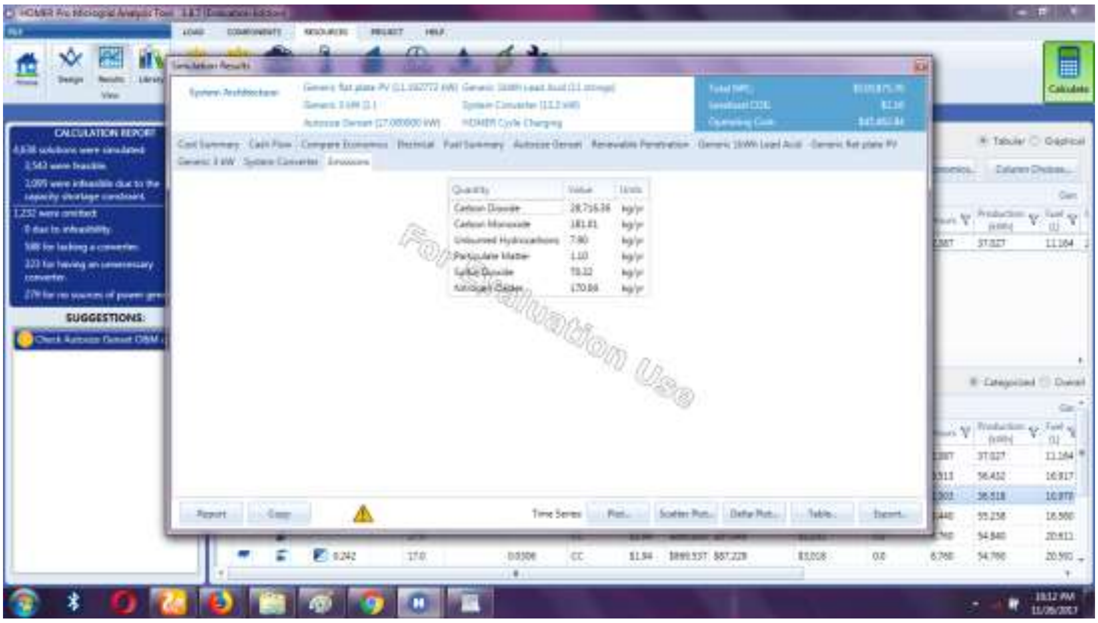


Figure 17: CO_2 Emission (kg/yr) for Diesel Price of $0.56/1 for Abraka



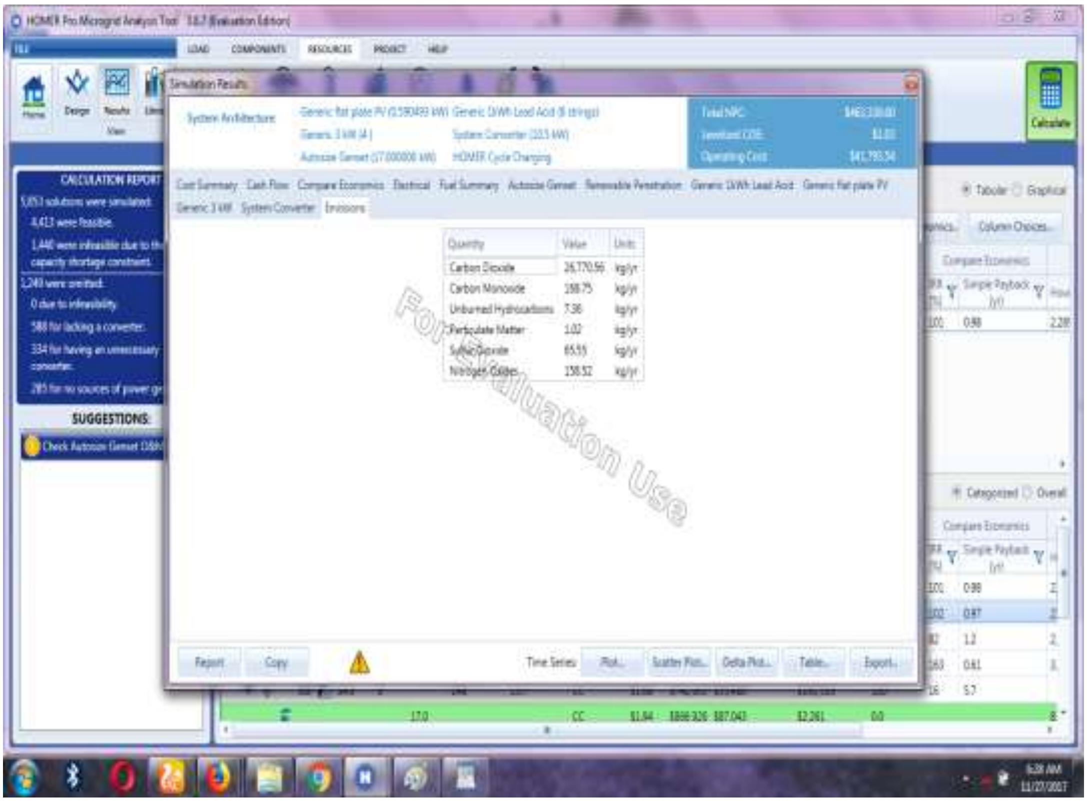
Quantity	Value	Units
Carbon Dioxide	25,424.68	kg/yr
Carbon Monoxide	160.26	kg/yr
Unburned Hydrocarbons	6.99	kg/yr
Particulate Matter	0.97	kg/yr
Sulfur Dioxide	62.26	kg/yr
Nitrogen Oxides	150.55	kg/yr

Figure 18: CO_2 Emission (kg/yr) for Diesel Price of \$0.56/1 for Iwofe



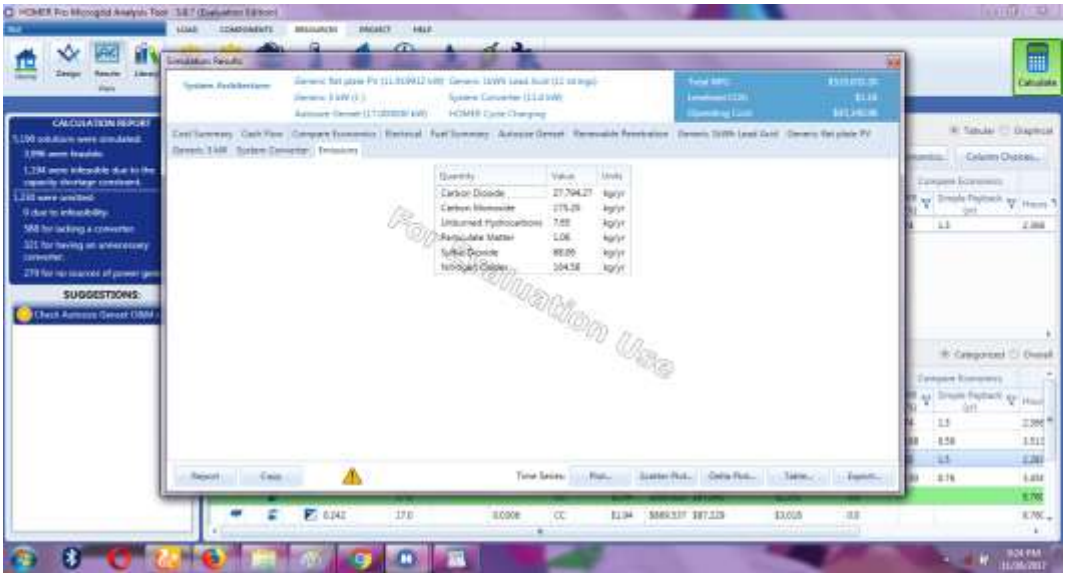
Quantity	Value	Units
Carbon Dioxide	28,716.36	kg/yr
Carbon Monoxide	181.81	kg/yr
Unburned Hydrocarbons	7.90	kg/yr
Particulate Matter	1.10	kg/yr
Sulfur Dioxide	70.32	kg/yr
Nitrogen Oxides	170.86	kg/yr

Figure 19: CO_2 Emission (kg/yr) for Diesel Price of \$0.56/1 for Okada



Quantity	Value	Units
Carbon Dioxide	26,770.56	kg/yr
Carbon Monoxide	168.75	kg/yr
Unburned Hydrocarbons	7.36	kg/yr
Particulate Matter	1.02	kg/yr
Sulfur Dioxide	65.55	kg/yr
Nitrogen Oxides	158.52	kg/yr

Figure 20: CO_2Emission (kg/yr) for Diesel Price of \$0.56/1 for Wilberforce Island



Quantity	Value	Units
Carbon Dioxide	27,794.27	kg/yr
Carbon Monoxide	175.29	kg/yr
Unburned Hydrocarbons	7.65	kg/yr
Particulate Matter	1.06	kg/yr
Sulfur Dioxide	68.06	kg/yr
Nitrogen Oxides	164.58	kg/yr

Figure 21: CO_2 Emission (kg/yr) for Diesel Price of \$0.56/1 for Edibe Edibe

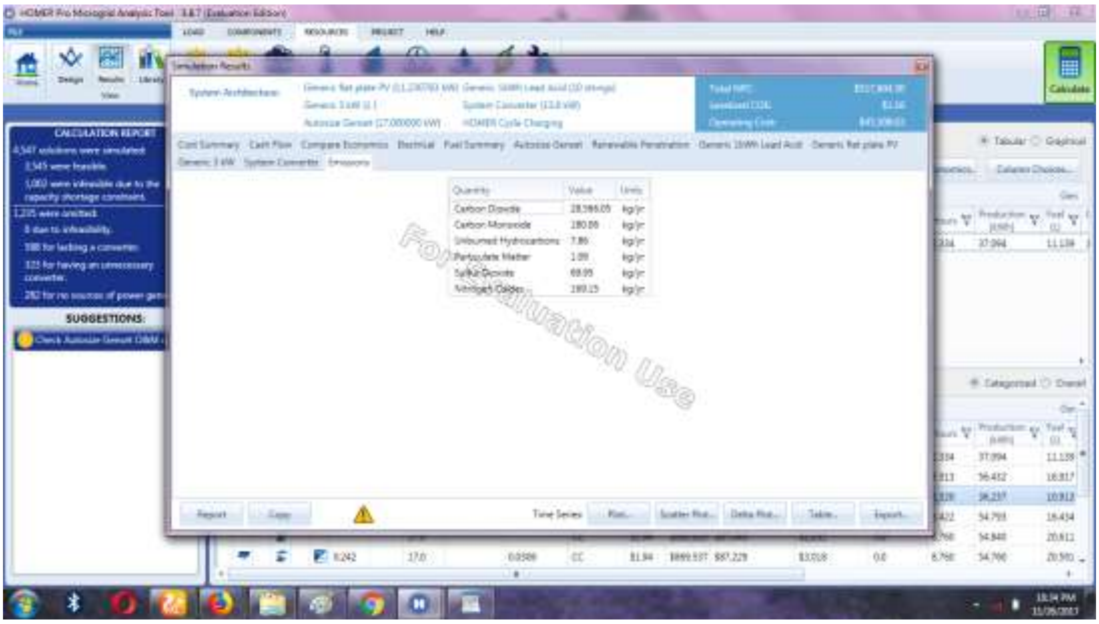


Figure 22: CO_2 Emission (kg/yr) for Diesel Price of \$0.56/1 for Ikpa road

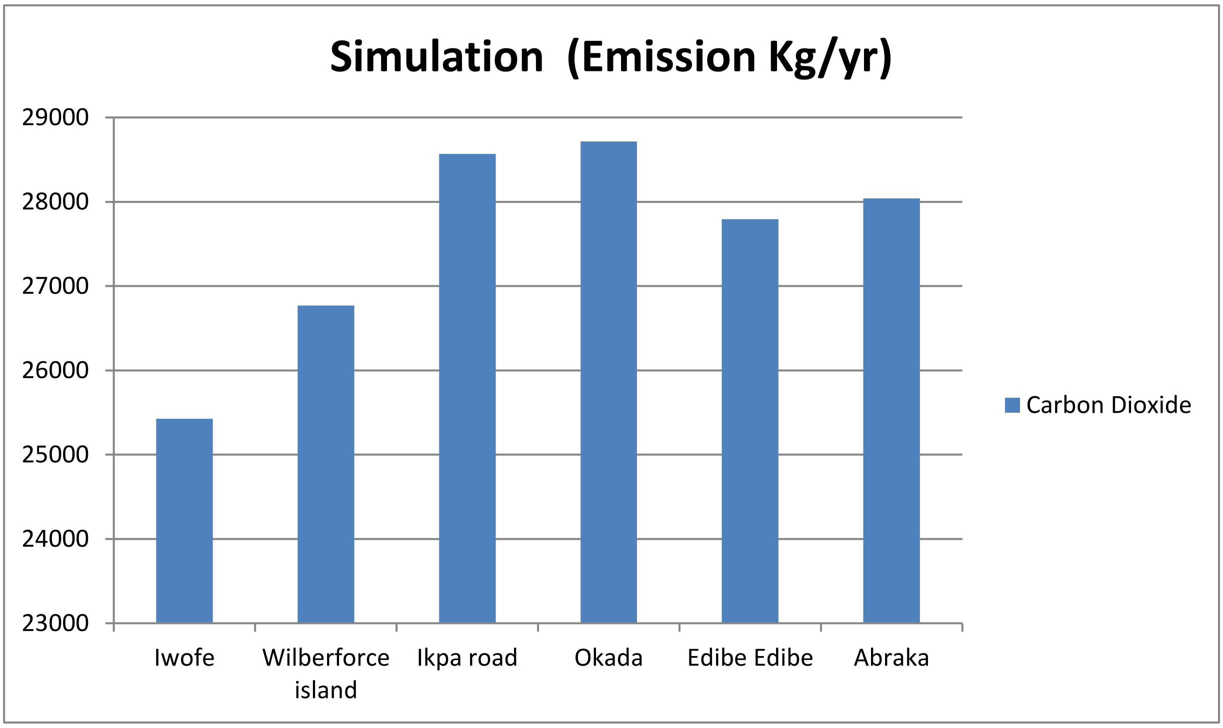


Figure 23: CO_2 Emission (kg/yr) for Diesel Price of \$0.56/1.

TABLE VII

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

6. Conclusion

This study examined the techno-economic viability of hybrid power systems at six chosen locations, one from each state in Nigeria's south-south region. The optimal system architecture, total costs, and environmental implications were quantitatively analyzed through an examination of resource availability in each state and simulations of entire system scenarios. 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. It is also possible to draw the following conclusions from the study's results for the chosen sites:

- Based on the NPC, the hybrid PV/wind/diesel/battery/converter renewable system configuration is determined to be the best architecture for sensitivity situations of $0.56/1. If the same standard is used and the same system configuration is deployed in all of the states, COE and RF calculations must be made. Wilberforce Island, which is in the tropical monsoon climate zone, is also the greatest and most ideal place to install a PV, wind, diesel, battery, and converter power system in the southern part of Nigeria.

- The total findings showed that the hybrid system configuration not only outperformed the base case simulation for the NPC for all six simulations, but also performed better in terms of electricity output, energy use, and CO2 reduction.

- For each state, Iwofe, Wilberforce Island, Ikpa Road, Abraka, Edibe Edibe, and Okada have the best system configurations with the lowest NPC. Iwofe also uses a wind/diesel/battery/converter system.

Data availability statement

Valuable data and pieces of information were obtained from, The Time and Date Weather global database. Available from: https://www.timeanddate.com/weather/Nigeria As well as Solar Electricity Handbook Available from: https://www.solarelectricityhandbook.com/solar-iradiance.html

Conflicts of interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article.

Funding statement

This study was conducted as part of the authors' employment at The University of Calabar in Calabar, Nigeria, and The Cross River University of Technology in Calabar, Nigeria, and was not specifically funded. It was done as a requirement for her staff's annual review for promotion activities.

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