OPTIMIZATION OF HYBRID ENERGY MIX FOR RURAL ELECTRIFICATION IN NIGERIA

B.O. Ariyo[1], M.F. Akorede[2], A. K. Adebayo[3]

[1,2]Advance Power and Green Energy Research group, Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria.
[3]Electrical and Electronics Engineering Department, Federal Polytechnics Ede, Osun state, Nigeria.

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Abstract - *Access to a stable and regular supply of electricity is paramount in advancing the well-being of any community, for it promotes economic advancement and creates employment opportunities for both middle age and young ones. Green energy systems are globally accepted as the most reliable energy sources, considering their numerous benefits, but with some drawbacks as they cannot be available throughout the year. The study focuses on the feasibility of applying renewable hybrid power system in Off-grid condition as an alternative energy supply systems to Kaba-Owode, a small community in the Kwara state of Nigeria that experiences epileptic power supply. The simulation result, using Hybrid Optimization Model for Electric Renewable (HOMER) revealed that the proposed system configuration was not optimal for the case study, as PV/Diesel/Battery came up as the most financially viable and sustainable solution to the case study energy demand.*

Key words: Hybrid system, HOMER, System configuration, Emission, Cost of energy (COE)

1. INTRODUCTION

Economic investment has been the major reason for poor supply of electricity. It is highly capital intensive to install large grid power systems over long distances to feed small isolated communities living in remote areas. Conventional technology provided by diesel generators is highly capital intensive due to high maintenance cost, persistent increase in fuel price and drawbacks related to noise, vibration, and emissions of greenhouse gases (GHG). The new solution from renewable hybrid power systems, which essentially utilize solar and wind energy, is experiencing tremendous growth in recent years [1-3]. Wind and solar energy are naturally accessible, environmentally compassionate and promising reliable power sources due to their topographical benefits for local power generations. Rising energy demand due to increasing population, global decline of fossil fuel reserves and intermittent increase in fuel price is the major reason for economic research into renewable hybrid power system as a modern solution to an incessant power outage in many countries [4-7].

The term "hybrid power system" describes a system where more than one energy source (wind, solar, biomass, hydro, diesel generator, etc) and storage systems are integrated to meet the required load demand at a particular period [8-9]. With respect to different energy sources, a renewable hybrid system may include alternate current (A.C) or direct current (D.C) inverter, back up storage system, and effective control mechanism for system stability. The entire loads are connected using different design configurations. Data acquisition devices are mostly used in renewable energy system's research work to collect data with respect to the installed system performance and for analysis purposes.

In this regard, renewable hybrid power systems have shown numerous benefits, among which are: reducing the depletion rate of fossil fuels energy reserves, supplying stable energy to residents in remote rural areas without any environmental hazard, as well as guaranteeing regular and stable power supply [10-12]. The most important advantage of the hybrid power system is improved system reliability when the renewable energy productions are used together. More so, the system total cost could be spread over the hybrid system life cycle. Many seasonal researchers have presented different areas of application of renewable hybrid power system, considering its remarkable benefits.

In [13] feasibility study of feeding two different load capacities: 5 kWh / day and 10 kWh / day throughout the year with Solar-Wind hybrid power system was performed, considering six different selected locations. The result revealed that, as the loading condition increases per day, the cost per unit reduces. Although, the initial hybrid cost was high but produces electricity at least cost. Sivaramakrishnan et al. in [14] research into design and implementation of hybrid power generation system, integrating Wind generator, PV solar cell array and Nano-antenna array, storage batteries, and inverter as an alternative solution to PV based Solar cells. Implementing the novel technology, Nano-antenna was able to absorb the incident solar radiations. The Nano-antenna targeted mid-infrared rays, which the earth continuously radiates as heat after absorbing energy from the sun during the day. In comparison, traditional PV solar cell can only use visible light, rendering them idle after dark, hence, less energy is captured. The integrated technology presents compact power generation with an uninterrupted power supply at minimum cost at all places at all time.

The ability to supply a remote village (Al-Qtqt) in Saudi Arabia with its needed energy demand using Hybrid renewable energy was investigated in [15]. Five different scenarios were simulated for the case study, using HOMER software. The result shows that "Solar-Grid without Wind" scenario was the optimal system configuration for the case study, because wind turbines are not feasible for the wind speed of less than 3 m/s, as presented by the case study. Sensitivity analysis, using Wind-PV-Battery hybrid power system as an alternative to grid extension was implemented in [16] to supply energy to Chittagong, a small community in the East-Southern part of Bangladesh. The community had annual load demand of 53,317 kWh. The result confirmed that; the maximum electricity comes from the wind which predicts that wind is more feasible than the solar at the site.

Atif Naveed Khan et al. [17] evaluated a renewable energy system for Off-grid rural electrification to bridge the gap between energy demand and energy supply in Pakistan. Baluchistan province, the most deprived community having no access to electricity was chosen as a case study. Three different renewable hybrid energy systems, in standalone mode, has been simulated and analyzed in HOMER software for the case study. The result shows that the rural electrification using a hybrid renewable energy system can act as a reliable solution for the community having no access to electric grid systems.

The main objective of this work is to research into the feasibility of feeding communities living in remote places with stand-alone renewable hybrid power systems for over a year. Kaba-Owode of the Kwara state, Nigeria was chosen for this purpose. There is global consensus that, among the various challenges facing the world today, greenhouse gas (GHG) emissions had the greatest negative impact on our environment. GHGs allow sun rays to enter the atmosphere; hence an increase in GHG emissions would amount to global warming or increment in the planet's temperature to levels that if not effectively reduced, it can threaten the global climate's stability which could be fatal to live organisms [18].

Basically, there is two accepted hybrid power system configuration: system operating mainly on diesel generators, while the renewable hybrid system is used for conserving fuel consumption, and system operating on renewable energy system with diesel generator used as a backup supply for periods of lower renewable energy input or peak load demand periods. The renewable sources of energy like wind, solar, hydro and so on can be considered as uncontrollable sources because their availability fully depends on the climatic weather condition. They supply energy with disturbances and represent primary energy sources [19].

Previous researches show that preference is given to renewable and low-carbon generation technologies due to the problems confronting conventional fossil fuel-based power generations [20-22]. Fig. 1 describes the proposed renewable hybrid system for the case study, comprising of Wind-Solar-Diesel generator and Battery storage unit. The system is designed to supply AC for domestic purposes

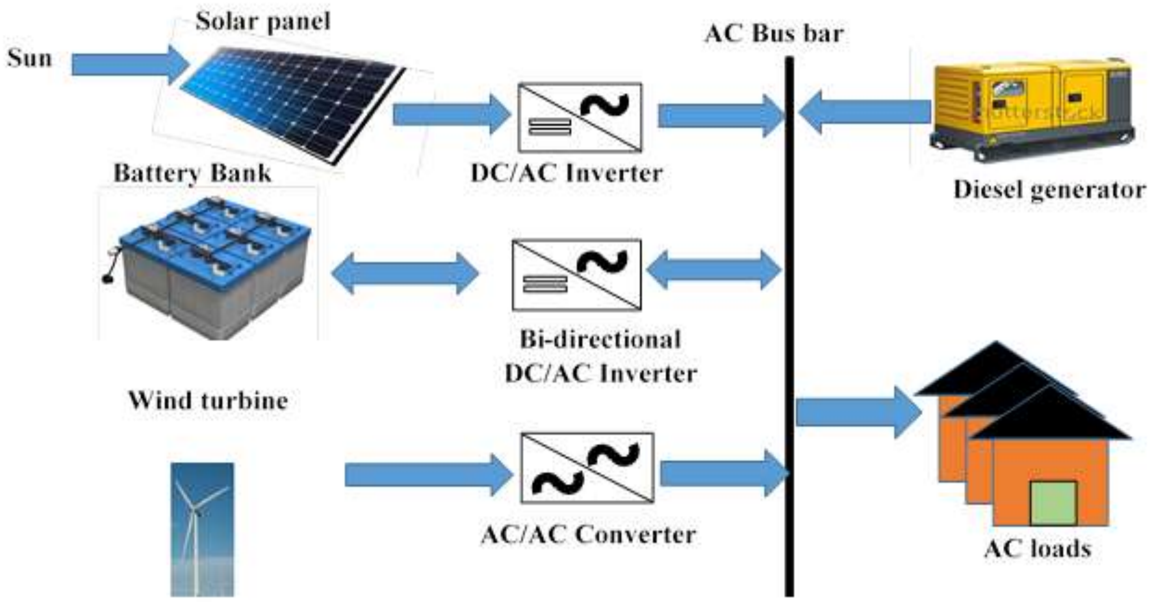

Fig. 1: Schematic diagram of a renewable hybrid power system

2. COMPONENTS OF HYBRID POWER SYSTEMS

A typical hybrid power system as shown in Fig. 1, may contain the following:

- Renewable energy sources (PV, Wind turbine, hydro turbine, biomass, and so on.);
- Diesel generator;
- Battery bank; and
- Power conditioning system.

2.1 Renewable energies are gotten from resources which are naturally replenished such as wind, rain, geothermal heat, tides, and waves. Solar, Wind, and biomass constitute the three major renewable energy sources. Considering the natural characteristics of renewable energies, they always dwindle in nature, unpredictable and unstable. Renewable energy systems adopt complementary nature of one another to optimize the output energy production.

2.2 Diesel generator (DG) performs the major role in realizing the hybrid power system's stability. Diesel generator serves as the main back up unit, supplying energy to rural areas where conventional grid systems have not been reached and in urban areas where people experience a regular power outage. In a hybrid power system, the battery storage unit and the renewable energy sources supply power to the load 24 hours of a day. If at some hours, the load demand cannot be met, the DG automatically starts and makes up for the needed energy demand. DG also performs a supporting role of battery charging and supplies power (inverters) to make up the energy demand.

2.3 Battery Bank: Renewable Hybrid power system needs some methods to store energy generated during a favorable climatic weather condition in order to use it during an unfavorable weather condition when the needed energy demand cannot be met. Among the various technologies employed includes: flywheels, compressed air, hydrogen production, etc. However, the battery has the highest benefits and reliability, in that it guarantees an uninterrupted supply of energy to the system loads during a power failure and unfavorable weather conditions, such as cloudy weather and at nights. Among available battery storage technologies, lead-acid batteries have continued to be the work-house of photovoltaic systems. Nickel–metal hydride, nickel–cadmium, lithium–ion, nickel–zinc technologies and lithium–polymer are the major competitors to the conventional lead-acid batteries.

2.4 Power Conditioning System: To realize the effective performance of hybrid power systems, energy converters are incorporated into the design system configuration. These are either electronic devices or electromechanical converter. Electromechanical power converters that are popularly used in hybrid renewable systems are of two types: rotary converter and synchronous condenser. The system requirement determines the one to be used. The basic switching components can either be power transistors (IGBTs) or silicon controlled rectifiers (SCRs). They are assembled to form a bridge circuit that generates oscillating waves form when switched ON.

3. TOPOLOGY OF THE CASE STUDY

3.1 Study area description

The renewable resources data used in this study are for Kaba-Owode community of Ifelodun Local Government, Kwara state, Nigeria. The community is located at latitude 8° 23′ N and longitude 4° 36′ E with 85 buildings.

3.2 Daily load demand assessment:

The electrical load consumption data of the site is based on data received from the Power Holding Company of Nigeria (PHCN), Challenge Business hub, Ilorin, Kwara state, Nigeria. Fig. 2 shows the 24 hours load consumption pattern of the site. It can be observed that the site experiences peak load demands of 35 kW between 6 am - 9 am and 40 kW between 8 pm - 10 pm, with minimum load demand of 20 kW per day.

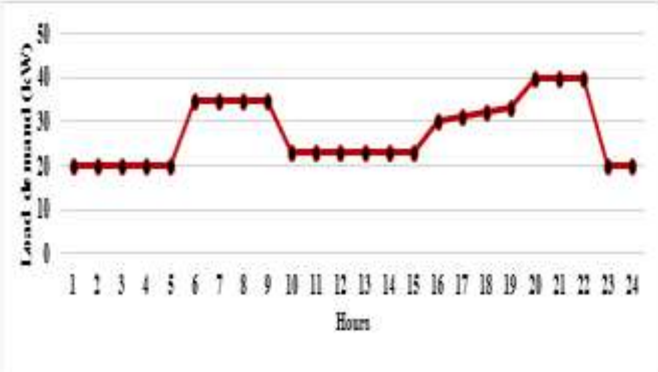

Fig. 2. Daily load demand curve of the case study

3.3 Wind speed resource

Considering the case study wind direction at an anemometer height of 10 meters above the surface of the earth, the community experiences daily average wind speed of 2.35m/s. This shows that the site experiences a weak wind speed capacity, hence many contributions should not be expected from the wind turbine in the proposed hybrid system. Fig. 3 presents the wind resource profile over a year period. This was gotten from NASA surface meteorology and solar energy website [23].

Fig. 3. Average Monthly Wind Speed at the Case Study Site

3.4 Global Solar resource profile:

Kaba Owode community favors the prospect of the hybrid power system plant in term of solar irradiance capacity. The average insolation of the community is 6.10 kWh/m^2/day. In this work, the monthly average global radiation data were obtained from NASA surface meteorology and solar energy website [23], to estimate the generation from the solar panel system. Fig.4. summarizes the monthly average solar irradiance of the site.

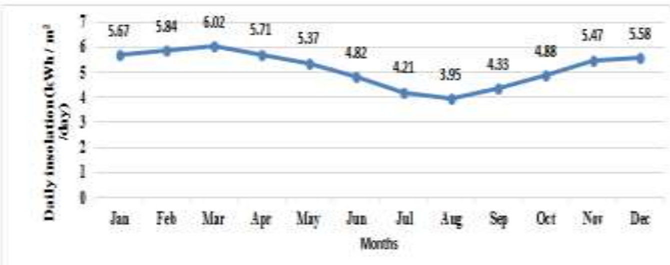

Fig. 4. Average Solar Irradiance value at the site

4. SYSTEM DESIGN AND SIMULATION

PV/Wind/Diesel/Battery hybrid system configuration is proposed for the case study. These energy resources are integrated together to harness the output power of the system, as well as to compensate for the unpredictable fluctuations in the climate using HOMER software. Homer has the ability to carry out simulation and sensitivity analysis of hybrid renewable energy systems, when the required data such as: system component's capacity values, capital cost, renewable energy resources values and daily load energy demand data are supplied into the HOMER software as in Fig. 5. The simulation process was carried out in the HOMER for efficient analysis of the proposed system configuration, considering the simulation parameters and constraints in table I & II.

Table I: Assumed system's component sizes and their cost summary

Solar PV Panel	
Capital Cost	$8000
Replacement cost	$7500
Operation & Maintenance cost	$0
Sizes considered	1, 2, 4, 6, 8 & 10 kW
De-rating factor	90%
Life time	20 years
Wind energy conversion system	
Capital Cost	$28000
Replacement cost	$20000
Operation &Maint. cost	$20 / year
Sizes considered	0, 1, 2, 3, 4 & 5kW
Life time	15 years
Diesel Generator	
Capital Cost	$5000
Replacement cost	$4500
Operation & Maintenance cost	$25 / year
Sizes considered	0, 5, 7.5, 10 & 15 kW
Life time	15 years
Battery	
Capital Cost	$175
Replacement cost	$175
Operation & Maintenance cost	$20 / year
Sizes considered	6V, 360 Ah
Number of units considered	0, 4, 8, 16, 32, 48 & 64
Life time	15 years
Converter	
Capital Cost	$200
Replacement cost	$150
Operat. & Maint. cost	$10/year
Sizes considered	0, 1, 2, 4, 6, 8 & 10 kW
Life time	10 years
Efficiency	95%

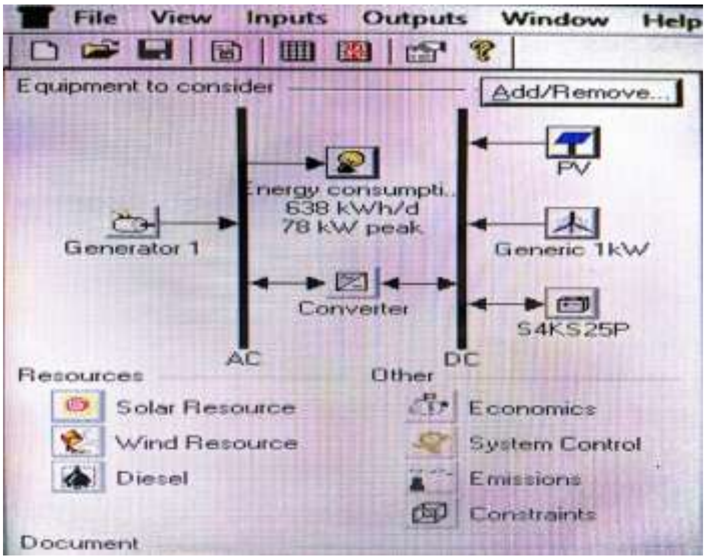

Fig. 5. Proposed hybrid system configuration for simulation in HOMER

Table II: Simulation parameters and Constraints

Parameter	Value
Project lifespan	25 years
Simulation time step	60 minutes
Annual interest rate	5%
Maximum renewable fraction	1
Maximum annual capacity shortage	3%
Dollar exchange rate	#356.50 / $ (2016)
Percent of annual peak load	0%
Percent of hourly load	5%
Percent of hourly solar output	50%
Percent of hourly wind output	50%

4.1 Economics, System constraints and Simulation

Parameters.

The project lifetime is taken as 25 years with an annual interest rate of 5%. Furthermore, the maximum annual capacity shortage penalty is given consideration and taken as 3% to guarantee system stability. By nature, renewable energy sources are not stable, which necessitate constraining conditions. Constraints are conditions that systems must meet to be feasible. Infeasible systems do not appear in the optimization and sensitivity results. Operating reserve provides a margin to account for intra-hour deviation from the hourly average of the load or renewable power output. HOMER calculates this margin for each hour based on the operating reserve output. Power systems must always provide some amount of operating reserve because the electric load tends to jump around randomly. Without operating reserve, the load would sometimes exceed the operating capacity of the system and create system disturbances.

5. RESULTS AND DISCUSSION

5.1 Optimal System Configuration: The optimization assessment has been carried out in Homer software. Five different feasible system configurations were simulated: PV/Diesel/Battery, PV/Wind/Diesel/Battery, Diesel/Battery, PV/Diesel, and Diesel only. The overall result is as presented in Fig. 6. The optimized result was calculated for the solar irradiance of 3.95

kWh/m²/day. PV/Diesel/Battery came up as the most optimal configuration, comprising of 30 kW PV array, 15 kW Diesel generator, 8 numbers of Trojan (L16P, 6V, 360 Ah) storage battery systems and 18 kW converter, with net present cost (NPC) of $575,901 (N205,308,706.50), and minimum cost of energy of $1.452/ kWh (N 517.64).

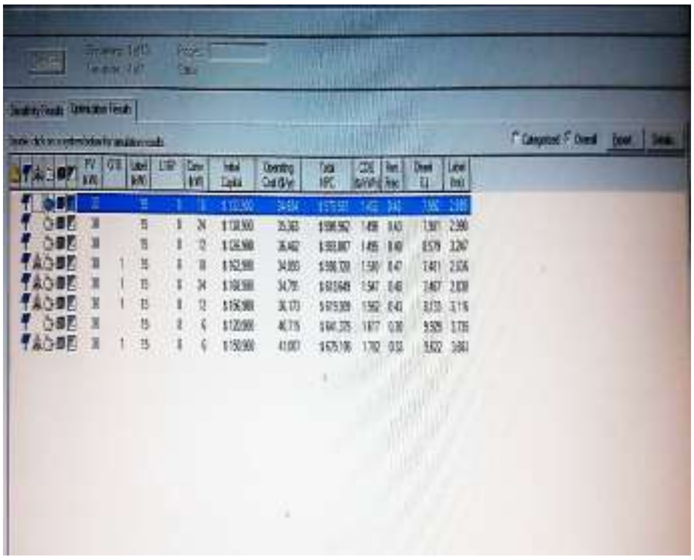

Fig. 6. Proposed hybrid system configuration for simulation in HOMER

The monthly energy mixes of the optimal system configuration are presented in Fig. 7. The PV has the maximum monthly electric contribution which reflects reduced emission system configuration.

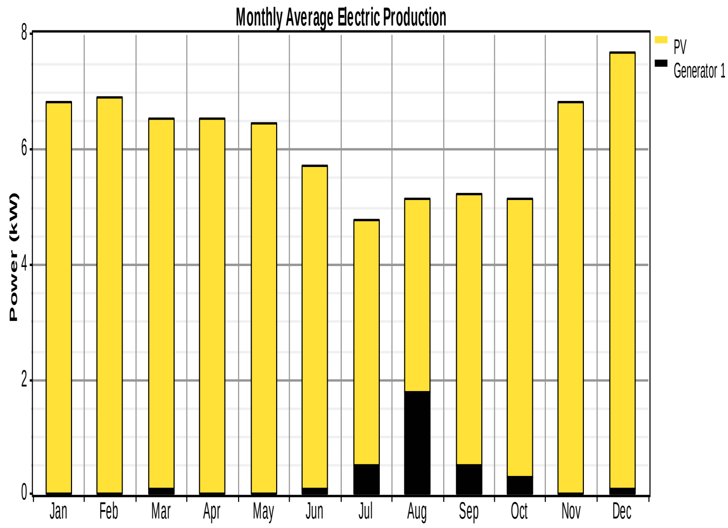

Fig. 7: Monthly Average Electric Production from the System Optimal Configuration

Fig. 8 is the investment contribution of the optimal system configuration components. It can be observed that the diesel generator took the bulk of the investment cost $410,563. The diesel generator cost has a great effect on the overall capital cost of the optimal hybrid system and also shoot up the per kilowatt-hour cost of the energy. Effective and friendly tariff scheme must be adopted to reduce the overall investment cost on the optimal system configuration, which will go a long way to bring down the overall kilowatt-hour cost of energy. Achieving this will make the capital project affordable for the case study community as well as other interested investors in renewable hybrid power system projects.

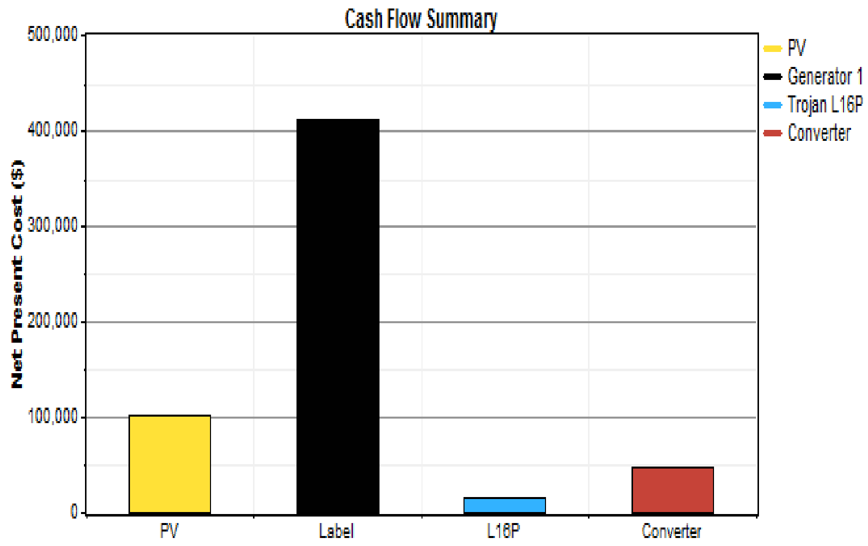

Fig. 8: Optimal System's Component Investment Cost

Table III: The Cash flow of the optimal system configuration

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV(30 kW)	90,000	28,062	0	0	-15,727	102,335
Diesel Gen.(15 kW)	22,500	36,587	287,146	64,365	-35	410,563
Battery (6V, 360 AH)	2,400	11,883	2,045	0	-449	15,879
Inverter (18 kW)	18,000	7,512	23,010	0	-1,398	47,124
System	132,900	84.043	312,201	64,365	-17,609	575,901

5.2 Sensitivity analysis result

The Sensitivity analysis was carried out on the system optimal configuration (PV-Diesel-Battery) to determine the condition under which it is technically and economically realistic to achieve the proposed system configuration for the case study, i.e PV-Wind-Diesel-Battery. To achieve this, different values of wind speeds and diesel fuel prices were considered. The sensitivity values considered for wind speed are: 3, 4, 5, 6 and 7 m/s and 0.2, 0.3, 0.4, 0.5, 0.6, 0.7 and $0.8 / litre for diesel prices. Fig. 9 presents the sensitivity analysis result. It can be observed from the figure that, the segment in green color shows the proposed system configuration condition for the case study. This can only be realized when the case study site's wind speed ranges between 2.7 m/s - 4.8 m/s, while the diesel price is above $0.4/litre.

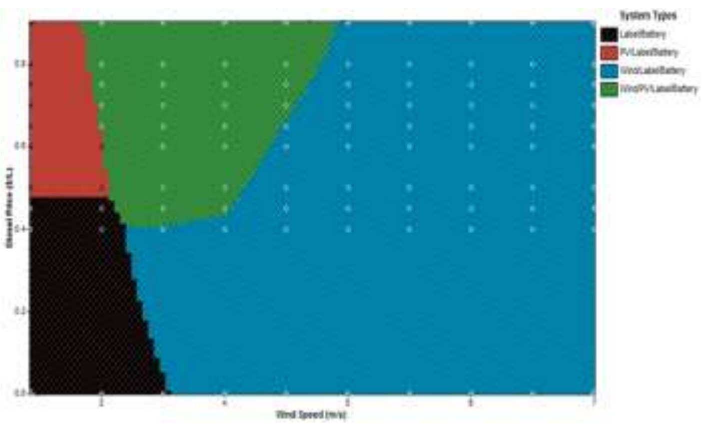

Fig. 9: Optimal System condition for Variable Wind Speed and Diesel Price

5.3 Optimal system's emission benefit

The quantity of CO_2 pollutant produced in the five scenarios considered in the work is shown in Fig. 10. The optimal system configuration had the lowest amount of emission when compared to other system configurations. This is a reflection that, more savings will be made on the liters of fuel to be consumed by the diesel generator per year, as well as additional savings on diesel generator operating and maintenance cost per year. The optimal system configuration guaranteed a safety and harmonious environmental condition for the case study community when implemented.

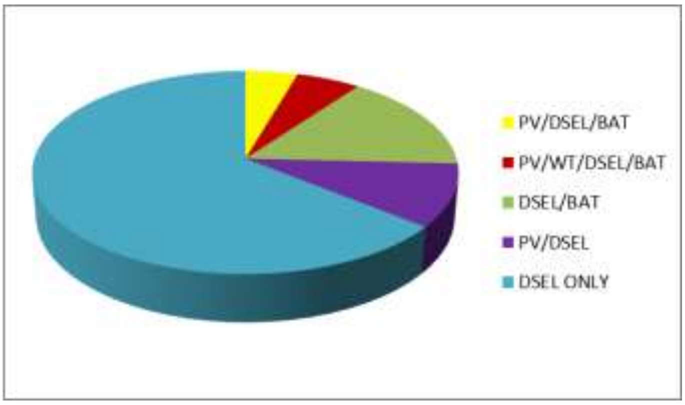

Fig. 10: Emissions pollutants in the hybrid scenarios

6. CONCLUSION

Nigeria, the giant of Africa with abundant natural and human resources, suffers a power shortage crisis, as the country generates below her energy demands (less than 6000 MW). Some companies folded up as they needed a regular power supply for their production, while many artisans drop their profession for alternative means of sustenance due to a regular power outage. Majority of people living in remote communities either experience epileptic power supply or are not connected to the Nation Grid systems. These and many other challenges retrogress the educational advancement of people in remote communities as well as their socio-economic development.

The result of this work confirms that hybrid green energy system is a realistic solution to the energy crisis in Nigeria and rural communities in particular, where the Nation Grid systems could not reach many households due to financial challenges or the topography of such communities.
The initial capital cost and per kilowatt cost of energy (COE) of the optimal system configuration seems high when compared to Nigeria's National Grid cost of energy. This can be made affordable when the Nigerian Government announces friendly tariff schemes that encourage many companies and individual to invest in renewable hybrid power systems, as well enact regulatory laws that will force many industries to reduce the number of kilograms of poisonous pollutants they release into the atmosphere.

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