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Special Issue

A Themed Issue in Honour of Professor Onukwuli Okechukwu Dominic (FAS).

This special issue is dedicated to Professor Onukwuli Okechukwu Dominic (FAS), marking his retirement and celebrating a remarkable career. His legacy of exemplary scholarship, mentorship, and commitment to advancing knowledge is commemorated in this collection of works.

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Sustainable Community Electrification: A HELIU Residency Case Study on Modeling an Optimal Hybrid Renewable Power Systems

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Abstract

With the increasing energy consumption globally and the growing need for an eco-friendly sustainable, reliable solution, hybrid systems combining renewable and non-renewable resources offer efficient economic solutions. This study explores a scalable solution in the development of an optimal Hybrid Renewable Power System (HRPS) towards a sustainable power supply to the growing community of Heliu Residency in Enugu State, Nigeria. And further emphasis was focused on the integration of Solar photovoltaic (PV) modules, energy storage units (ESU), and small natural gas power plants (SNGPP). The research considered the estate's average and peak demand to optimize the HRPS primary component in minimizing energy, and annual operational costs (AOC), and achieving high system availability. The current deregulation in the power industry and downstream oil and gas sector has led to skyrocketing energy tariffs and higher energy costs with conventional alternatives. The base case, being the national power grid yielded a COE of $0.127/kWh. In comparison, the optimized HRPS configuration (200kW PV, 200kW SNGPP, 700Kwh ESS) achieved a COE of $0.0394/kWh about N66.98 at N1,700 per $1, with an initial capital cost (ICC) of $151,500 about N257million at N1,700 per $1, an AOC of $24,610 about N42million per annum and a total net present cost (TNPC) of $32,998,500. The proposed system showed zero unmet loads, zero capacity shortage, and a 5kWh/day excess energy with a renewable penetration fraction of 43.1%. The proposed system showed an improved performance considering the key metrics as compared to the base case economically, further enhancing sustainability and scalability.

Keywords: Hybrid, Renewable, Power, Sustainability, and Community.

1. Introduction

Electrical energy defines so many areas of our lives that it has become a necessity. The continuous population increase resulting in the increasing energy consumption crisis across the globe has become one of the major challenges facing energy developers and Nigeria, in particular Enugu State is not left out. As a result of the geolocation of the State in the Eastern bloc, its historic narrative, and the international airport, the influx of residential seekers has been on the rise further constricting the strained grid supply. There has been a significant drop in the power supply quality, duration of supply, and overall grid instability as a result of these technical imbalances. To make up for this energy shortfall, users' resort to the use of all grades of alternative fossil fuel resources for their power generation especially Premium Motor Spirit (PMS) or Diesel. Conventional energy sources are plagued with several issues. The major drawback of conventional energy systems is the cost of expansion and the ecological impact in finding the right of way for the infrastructure. And the proposal for a distributed energy source mitigates this challenge in addition to accrued potential. Energy sources are generally divided into two major groups: non-renewable and renewable energy sources. Non-renewable energy sources, such as crude oil, natural gas, coal, and uranium, are limited in supply. In contrast, renewable energy sources are unlimited and include solar energy, biomass resources, wind power, and hydropower. Notably, solar energy is the primary source of most renewable energy, with biomass, wind, and hydropower being secondary derivatives. Other non-solar renewable resources are geothermal and tidal energy. Current demand in energy generation and distribution requires sustainable measurable that'll make the system resilient and reliable.

Recently, renewable energy resources (RER) have been universally recognized as the most effective means of mitigating carbon footprints and global warming. It has been used to generate electricity to address most of the conventional resource challenges. Renewable Energy Sources (RES) offer a viable and potentially affordable alternative for energy supply, with the potential for easy scalability. However, due to their intermittent nature, RES alone cannot provide a reliable and cost-effective energy-generating system. To address this limitation, intermittent renewable energy sources require complementary support (Osalade et al, 2022). To mitigate the limitations of individual energy sources, hybrid systems combining two or more energy sources are being developed. These hybrid systems offer several benefits, including optimized power production costs, reduced emissions, enhanced reliability, and improved sustainability (Ozue et al., 2024).

Nigeria's power sector faces a significant challenge in diversifying its electricity generation. Despite being richly endowed with both renewable and non-renewable energy sources, the country struggles to determine the most technically and economically efficient option. The development of hybrid energy systems must involve various forms of enhancement associated with operation and component selection to ensure a reliable and competitive power supply. Optimal sizing of HRES is crucial to avoid oversizing, which increases costs, and under-sizing, which compromises system reliability (Opedare et al, 2020). Optimal sizing is essential for assessing the performance of hybrid power systems, considering both their techno-environmental impact and economic viability. However, most existing hybrid power system (HPS) models are prohibitively expensive, overly complex, and difficult to adapt to local conditions, making them unsuitable for community electrification in developing regions.

So much research has been done in HRES to develop an alternative HPS to ameliorate the challenges faced by community-based energy infrastructure both as islanded or grid-tied configuration. These systems work towards addressing the constraints and minimizing or maximizing the objective functions using different techniques. Haghighat et al (2016) proposed a Solar Home System (SHS) for an off-grid community with more than 500 densely populated households. The techno-economic analysis conducted showed that the proposed system was more economically a viable option for the community. Adaramola et al 2014 used Hybrid Optimization of Multiple Energy Resources (HOMER) to conduct an optimization analysis on a solar/wind/diesel generating unit configuration for a hypothetical remote village in Ghana. Homer software was also used to analyze an islanded PV/WT in Kenya (Anastasopoulou et al, 2016) with NPC as the objective function. The system comprising a 100kW WT, an 80kW PV, and a 60 Surrette 4KS25P battery generated 791.1 MWh of energy at a COE of $0.281 per kWh. In 2020, Rezk H. et al simulated a PV/FC/Battery system for seawater desalination at Saudi NEOM and on the other hand, a techno-economic feasibility study of a Micro_Hydro/PV/Diesel/WT/Battery system for an electrification project in a remote village in southern Nigeria (Oladigbolu et al, 2020) was studied. Multiple performance metrics were used to assess the proposed model which are excess energy, LCOE, NPC, capacity shortage, and carbon dioxide emission savings.

Mokhtara et al, (2021) considered a single objective function for modeling an HRES in 7 locations in rural Algeria using PSO for optimization of COE. The PV/WT/Diesel/Battery performed better at 2 locations whereas PV/Diesel/Battery did better at the remaining 5 locations at a COE of $0.21 per kWh. A proposal by Kenu. et al 2022 on a sustainable power supply solution for a Public-Private-Community-Oil & Gas Partnership (PPCOP) funded model to present the most workable lowest cost energy delivery to consumers. Notably, a greater percentage of the power components were donated to the project. In Araoye et al 2024, multiple optimization algorithms were used to compare the multi-objective function techno-economic analysis of a standalone microgrid for the Nsukka community comprising 88 villages. A combination of Grasshopper Optimization Algorithm (GOA) and Homer was deployed to obtain a Total Net Present Cost (TNPC) at $1,198,997 and a COE of $0.01783/kWh for a Biogas/Diesel configuration. From a hypothetical remote village through donated power equipment to an actual community-enable off-grid system, these works concentrated majorly on the well-known conventional energy resource integrated with PV, Wind, or Biomass. Non-considered the use of Natural Gas as an alternative to Diesel in an Off-grid system or grid-tied. The key component rates were based on international pricing which is very much different from local reality while considering inflation and foreign exchange volatility. The energy demand profile of the case study of most of the reviewed works was based on the estimated load consumption of individual household appliances, not on the actual power consumption data.

Hence, this work considered modeling an economically viable Hybrid Renewable Power System (HRPS) by integrating a small natural gas power plant (SNGPP) which burns better than diesel generator with lesser fueling cost in the RES to form an HPS model to improve the techno-economic metrics using Homer with actual load profile data of Heliu Residency. One of the measures of the study was to focus on conducting an optimal sizing analysis for a Hybrid Renewable Power System (HRPS) using the actual load profile of the Heliu community. The primary objective was to design and evaluate a Hybrid Power System (HPS) consisting of solar PV, battery storage, and natural gas generators for Heliu Residency in Enugu State to project an economic viable solution with competitive tariff structure compare to the base case. The evaluation aimed to minimize annual operational costs (AOC), ensure high system availability, and meet the community's energy demands. This study is a pioneering effort in the selected community, and its findings are expected to unveil a lucrative business opportunity for stakeholders involved in Micro-Energy Distribution (MED) in Nigeria.

This research work is arranged as follows: Section 2 presents an explanation of the method and materials used in conducting the research which includes the study area, data collection, the mathematical model of the primary component, and representation of the economic model function for further analysis of the system performance in using Homer optimization platform. Section 3 discussed the performance outcome of the selected system configuration simulation results in light of the objective functions and system parameters. Section 4 provided the summary of the whole paper.

2.0 Materials and methods

In this study, the necessary parameters for Renewable Energy Sources (RES) were gathered from various sources. Solar data was obtained from the National Aeronautics and Space Administration (NASA) or National Renewable Energy Laboratory (NREL) database site, load profile data was collected from the estate's electricity management company (OEX), and Natural Gas Generator (NGG) parameters were sourced from manufacturers' price lists. The collected data was utilized as input in HOMER Pro software to model the hybrid system. The proposed system model is illustrated in Fig. 1a. Homer Software requires that the geographical number locator of the site under consideration be input as the location pointer during location weather information download fron NASA or NREL site during the configuration setup. Additionally, the geographical location number of the community was determined using a handheld Garmin Etrex GPS device, with the location pinpointed in Fig. 1b for better accuracy. The proposed system model as designed in Homer Software consist of a SNGPP, an Inverter, PV modules, ESUs, and the electric load of the community all represented in a single line diagram, all connected to their respective Buses. The design is a hybrid Bus system for ease in energy transformation and power management.

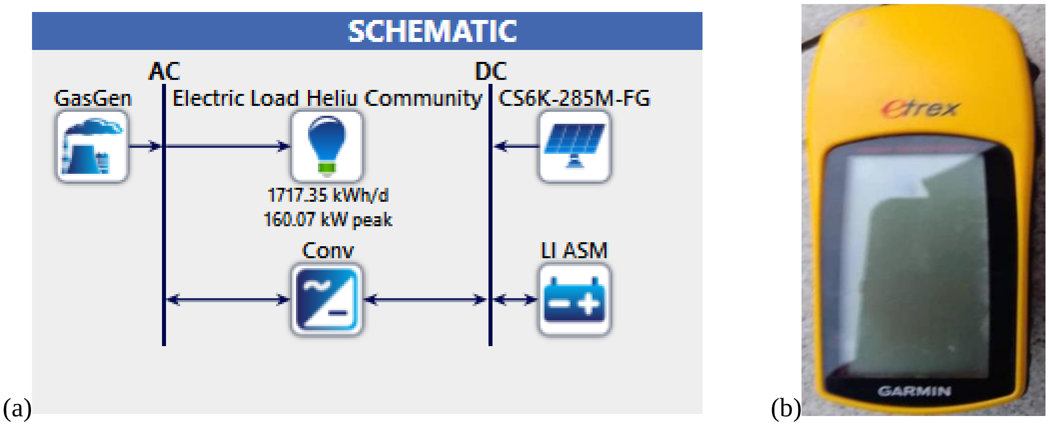

Figure 1: (a) Proposed System Schematic and (b) Garmin Etrex Handheld GPS device.

This methodology employed the following key components: Load profile analysis of the selected area, Assessment of temperature and solar resources, Definition of system units, Mathematical modeling and description, and Configuration of the hybrid energy system.

2.1 Description of Study Area

This study examined the energy situation in a community located in the southeastern region of Nigeria, specifically at the geographical coordinates of Latitude 6.41 and Longitude 7.55. The Community was designed to hold 2000 housing units but it is currently having over 220 units of household. The community is supplied by a 33kv feeder from Enugu Electricity Distribution Company to a step-down substation of 500KVA 33/0.415K. The community's current peak load demand is approximately 74.6 kW. The objective function of the technical, economic, and environmental analysis of this study was based on factors such as solar irradiation, fuel costs, and daily load demand. The required climatic data, including irradiance and ambient temperature, were obtained from NASA's satellite database website by specifying the community's geographical coordinates (latitude and longitude).

2.2 Load Profile Analysis

This analysis involves examining the community's energy consumption patterns to understand their load demands. The load demand profile used in this work was calculated based on power consumption data provided by OEX. Figure 2 illustrates the daily power consumption patterns of a typical suburban developing community during the rainy season (March-October) and the dry season (November-February). As anticipated, energy demand is higher during the wet season compared to the dry season. To validate the hybrid configuration, the daily load demand of a typical household in the community was used as the hourly load input in HOMER, generating a 24-hour load profile. To enhance system reliability and accurately capture daily fluctuations, a daily randomness of 15% and a time-step randomness of 10% were applied.

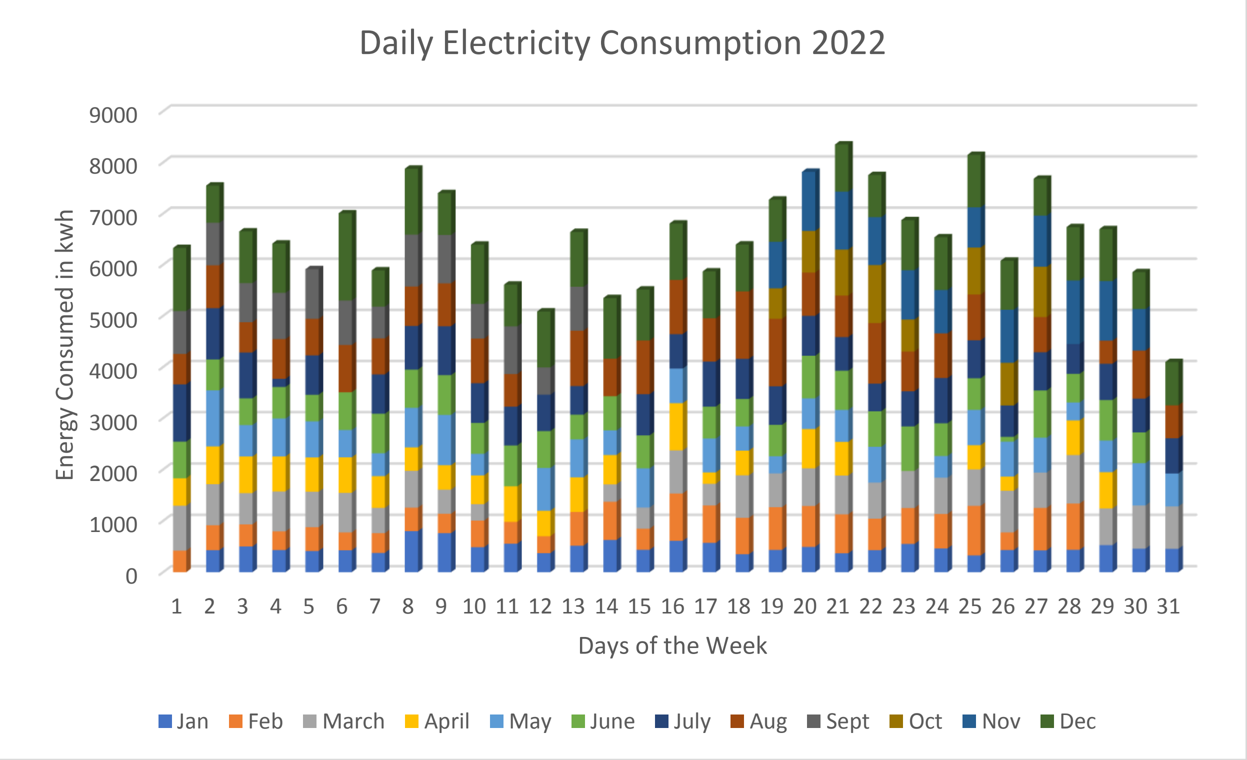

Figure 2: Daily electricity consumption from January to December of 2022.

According to the computed data, the total energy demand of the site under investigation showed that the lowest demand occurred in June whereas it peaked in October. An overall increase in demand was observed between August and December Figure 3.

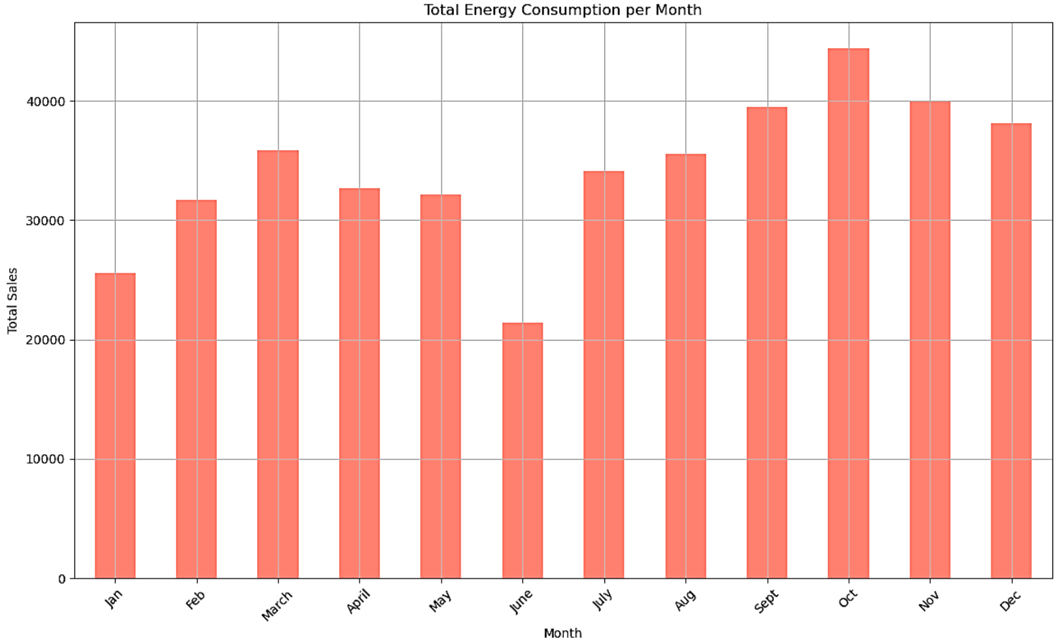

Figure 3: Total Energy Consumption per Month.

2.3 Solar radiation and temperature

The hourly Solar irradiance within the period under investigation was obtained from the National Renewable Energy Laboratory (NREL) database for the study area location. The Global Horizontal Radiation (GHR) irradiance data was adopted and used as the average daily irradiance as in Figure 4. More so, the community receives an average annual solar irradiation that ranges between 3.76 and 5.47 kWh/m^2/day and an overall average of 4.94 kWh/m^2/day. The study area experiences two major seasonal changes of which the dry period spans between November and March, and the rainy season lasts from April to June. Solar irradiance drops drastically during the rainy period, the months of July and September with increased intermittency as a result of cloudy sky.

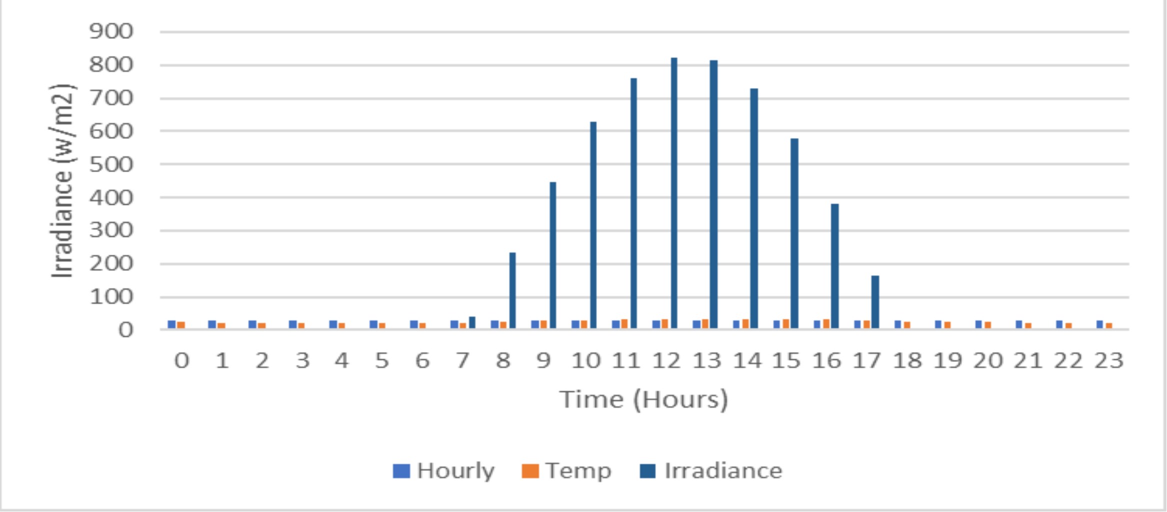

Figure 4: Average Daily Irradiance.

2.4 Natural Gas

Natural gas CO_2 emission content is lower than that of diesel and Nigeria sits on the largest reverse in Africa. Natural gas can also be obtained through other chemical processes and blending. The Nigerian Midstream and Downstream Petroleum Authority recently announced that the Domestic Base (DB) price was $2.42 per Million Metric British Thermal Units (MMBTU) following the requirements of the Petroleum Industrial Act (PIA) (https://www.nmdpra.gov.ng/DailyGas). Foreign exchange and product conveyance medium were critical factors that greatly influenced the price variation in the gas market. Therefore, this price will differ from region to region depending on distance, road accessibility, and regional security.

2.5 System Overview and Component Specifications

The HRPS under study comprises four major components: the PV, natural gas generator (NGG), storage unit, and a power converter. The proposed system was simulated and analyzed in a practicable scenario for the community under investigation using Homer Pro. The proposed system controller utilizes the following strategy to meet the load demand. The renewable power generators (RPG) serve the load during the day while the gas generator is in a floating mode and the excess electricity on the network is stored in the battery bank. This reserved energy is used if the RESs are unable to meet the required energy demand under the off-grid scheme adequately. The auxiliary gas generator operates as a floating backup power source. Therefore, precise system integration of primary components is anticipated in other to discover the necessary and achievable operational benefits. In the proposed design model, several parameters were varied so to make sure that the conditions projected for sustainable system configuration were achieved, in addition to reconnoitering the functioning of the design model. Nevertheless, the optimal performance is expected from the configuration to be better than any other variation that arises during the project's operational lifetime. Table 1 presented detailed information on input parameters for individual components along with their lifespan, model specification, and costs of the main components of the HRPS.

Table 1. Specifications and cost implications of various system components.

Component Parameters	Specifications
Solar PV System	
PV Rated Capacity	200kW
Capital Cost (CC)	$34,000
Replacement Cost (RC)	N/A
Operating & Maintenance Cost (O&MC)	$2,000
Battery Storage System	
Rate Capacity	120kWh
Nominal Voltage	12.8V
Capital Cost	$80/kWh
Replacement Cost	$85/kWh
Operating & Maintenance Cost	$1/kwh/Yr
Inverter System	
Rated Capacity	200kW
Capital Cost	$18,000
Replacement Cost	$1,419,000
Operating & Maintenance Cost	$13,400
Natural Gas Generator	
Rated Capacity	200kW
Capital Cost	$14,000
Replacement Cost	$4,200,000
Operating & Maintenance Cost	$33,105,000

2.6 Mathematical Model

2.6.1 Solar PV Model

The solar PV modules are made up of solar cells connected in a series or parallel to achieve the needed output specification of each unit. This connection technique is aimed at utilizing the PV module to generate and supply power for different applications. Overall, each PV module output power depends on the cell temperature, solar irradiation, and the material characterization of the cells that describe its series and shunt resistances (Ozue et al, 2024). The PV module's output power is calculated in Homer as follows (Nacer et al, 2016):

$$P_{pv} = P_{pv\_rated} D_F \frac{G}{G_s}\left[1 + \alpha_p (T_c - T_{STC})\right] \tag{1}$$

where P_{pv_rated} represents the solar PV module rated power output under standard test conditions (STC) in kW, D_F represents the solar panel de-rating factor (%), G is the irradiance incident on the solar panel (kW/m^2), G_s is the incident solar radiation obtained under STC (1 kW/m^2), α_p is the temperature coefficient of power (%/^{0}C), T_c represents the temperature of the solar panel (C), and T_{STC} is the solar panel cell temperature at STC (25 ^{0}C). The derating factor refers to the reduction in the PV array output resulting from temperature effects or any other associated factors that vary the expected output of the PV system under absolute conditions (Maleki et al, 2014).

2.6.2 Natural Gas Generator Consumption Model

Natural gas as a power fuel for generators produces lesser CO_2 emission as compared to diesel fuel. It serves as a good alternative to the use of diesel generators for the reduction of carbon footprint (Ozue et al, 2024). Therefore, renewable energy source generators will achieve higher environmental conditions, and improved performance in hybrid power generation (Araoye et al, 2023). This energy source operates like an uninterrupted power source in different configurations of hybrid power systems and is characterized by its power efficiency and fuel consumption rate. In this study, the Natural gas generator unit is projected to feed the network load, and the net supply is used to charge the battery based on the SOC. The fuel curve and linear correlation of the type of fuel used are vital parameters that affect the computation of fuel consumption of synchronous generators. Fuel consumption is the quantity of fuel utilized to generate electricity and is obtained from:

$$NNG_c = \mathrm{A}_{fc} RC_d + \mathrm{B}_{fc} PO_d \tag{2}$$

where NNG_c, A_{fc}, RC_d, B_{fc}, PO_d represent natural gas generator fuel consumption rate (L/h), fuel intercept coefficient (L/kWh), rated capacity of the natural gas generator, the fuel slope (L/kWh), and the power output of the generator respectively. However, A_{fc} and B_{fc} were taken to be 0.0161 L/kWh rated and 0.2486 L/kWh output (Maleki, et al, 2014), respectively.

2.6.3 Battery Storage System

To improve the power quality and overall performance of the system, a battery storage system is required for storing energy in a chemical form and is utilized during RE intermittency and power shortage in the systems. However, in general application, energy stored in battery units is expected to start operation and supply energy when the power output level of the RE system is low and unable to adequately serve the external load demand. Over the years, lead-acid type of battery storage unit was a common technology in the energy storage industry and also widely applied in power stabilization (Ozue et al, 2025). Recently, lithium-ion batteries are currently dominating the energy storage unit (ESU) market for decentralized hybrid power systems due to their extended lifecycle and performance efficiency (Araoye et al, 2024). The storage capacity of this system is calculated based on autonomy days and demand as follows (Ramli et al, 2018):

$$C_{batt} = \frac{E_L AD}{\eta_{inv} DOD \eta_{batt}} \tag{3}$$

$$C_{batt}(AH) = \frac{E_L AD}{\eta_{inv} DOD \eta_{batt}} \div V_{bus} \tag{4}$$

Where E_L is the average energy per day (kWh/day), AD as the autonomy days, η_{inv} describes the inverter efficiency (95%), DOD as the depth of discharge (80%), η_{batt} represents the battery efficiency (85%), and V_{bus} represents Battery Bus Voltage.

Therefore, the Battery bank aggregate capacity (AH):

$$C_n(AH) = \frac{N_{batt}}{N_{batt}^S} C_{batt}(AH) \tag{5}$$

Where N_{batt} denotes the number of batteries, N_{batt}^S represents the number of series-connected batteries

2.7 Economic and Environmental Criteria

The HOMER pro software helps developers simulate and optimize chosen metrics that are key in developing the test system model in terms of economic and environmental impact. The developed system model primary component parameters were optimized linearly in HOMER and minimized or searched for the system with the least total net present cost (TNPC). The TNPC is achieved through a computation involving initial capital cost, replacement cost, fuel cost, salvage cost, maintenance costs, and the revenue from sale-back if the system is grid-tied. As a result of some economic variation, the mathematical computer of NPC is proved to be more reliable as an economic metric than the levelized electricity cost, which is somewhat arbitrary (Haghighat et al, 2016). The TNPC is computed as (Araoye et al, 2024):

$$C_{A\_total} = C_{A\_cap} + C_{A\_rep} + C_{A-O\&M} \tag{6}$$

$$minTNPC = \frac{C_{A\_total}}{CRF(i,n)} \tag{7}$$

where C_{A_total} represents the total annualized cost ($/year), n is the lifespan of the project (year), i as the annual real interest rate (%), and CRF is the capital recovery factor, which is a function of i and n (Aziz, A.S. et al, 2019):

$$CRF(i,n) = \frac{i(1+1)^n}{(1+i)^n - 1} \tag{8}$$

The current inflation and interest rates in Nigeria stand at 32.46% and 27.8% (CBN, 2024), respectively. HOMER, therefore, applies the equation below to find the annual real discount rate (or real interest rate):

$$i = \frac{i' - f}{1 + f} \tag{9}$$

where i is the current interest rate, f as the anticipated inflation rate, and i' denotes the nominal discount rate.

The system cost of energy (COE) is the average energy cost per kWh of effective electricity generated by the system. HOMER applies the following expression to evaluate COE (Kenu et al, 2022):

$$COE = \frac{C_{A\_total}}{E_s} \tag{10}$$

$$E_s = L_{prim} + L_{def} \tag{11}$$

where E_s is the annual energy supplied, L_{prim} and L_{def} are the overall total power demand by the system per year (primary and deferrable load).

The amount of gaseous pollutants released to the environment depends on the volume of natural gas consumed during the generator's operation. These harmful substances are generally called greenhouse gas emissions (GHGs). In the hybrid generation system, the injection of renewable energy into the power system is expected to eliminate the resultant volume of these substances greatly. In this study, CO_2 emissions are used to examine the environmental impact of the proposed hybrid energy system.

Moreover, the overall quantity of CO_2 a hybrid power system generates will depend on whether the system includes non-renewable energy sources. HOMER computes the emissions factor for individual pollutants before the simulation and multiplies this factor by the net annual fuel consumption to determine the annual emissions of each pollutant at the end of the simulation.

3.0 Result and Discussion

3.1 Optimization Result

The average power demand and energy consumed by the community was 71.56kW and 1,717.35kWh respectively. The load random variability was set at 10% day-to-day and 20% timestep using a 60-minute time step size throughout 1yr. During the simulation, 24 solutions were simulated: 3 were omitted for lack of converter, 2 were discarded for having oversized converter, 8 were omitted for generating source unavailability, 4 were infeasible due to capacity shortage, and 7 feasible power generation solutions for HELIU Residency. The most economically viable generation sources configurations were selected and the outcome of their metrics were listed in Table 2. The four most viable configurations were PV/NGG/BESS, PV/DiG/BESS, DiG and NGG generating systems. According to the economic metrics under focus in this study, the PV/NGG/BESS configuration performed better than the other configuration in the key metrics like the COE, AOC. The ICC performance of NGG and DiG looks very incentive on the short term but over the operational cycle of the system, the AOC and TNPC showed that they were more expensive to run over the project life cycle. The result also showed that NGG were cheaper to run over a longer period that DiG though the latter is cheaper to setup. From the result, the PV/NGG/BESS configuration had the lowest fuel consumption as compared to the rest and also a moderate utilization of the ESS thereby improving the cycle life.

Table 2: Economic viability Results of selected optimal generation sources configurations

Component Configuration	PV	Fossil Generator	Ave. ESS/day	Ave. Fuel Cost/day	COE	TNPC	AOC	ICC
PV/NGG/BESS	187kW	160kW	191kWh	$28.3	$0.039	$32,998,500	$24,610	$151,500
PV/DiG/BESS	187kW	141kW	397kWh	$488	$0.314	$262,642,900	$196,672	$148,500
NGG	0	200kW	0	$49.8	$0.086	$71,642,140	$53,663	$19,000
DiG	0	275kW	0	$905	$0.667	$557,348,100	$417,579	$16,000

3.1.1 Solar Output

The PV array is made up of Canada Solar Panel CS6K-285M-FG with a cumulative capacity of 200kW. The array produced a maximum output of 187kW, a mean output of 32.4kW, and a capacity factor of 16.2%. The PV generator produced a total of 283,436kWh of energy per year. Figure 5 depicts the PV power output per year revealing that production was higher during the dry season as a result of high radiation and clearance index.

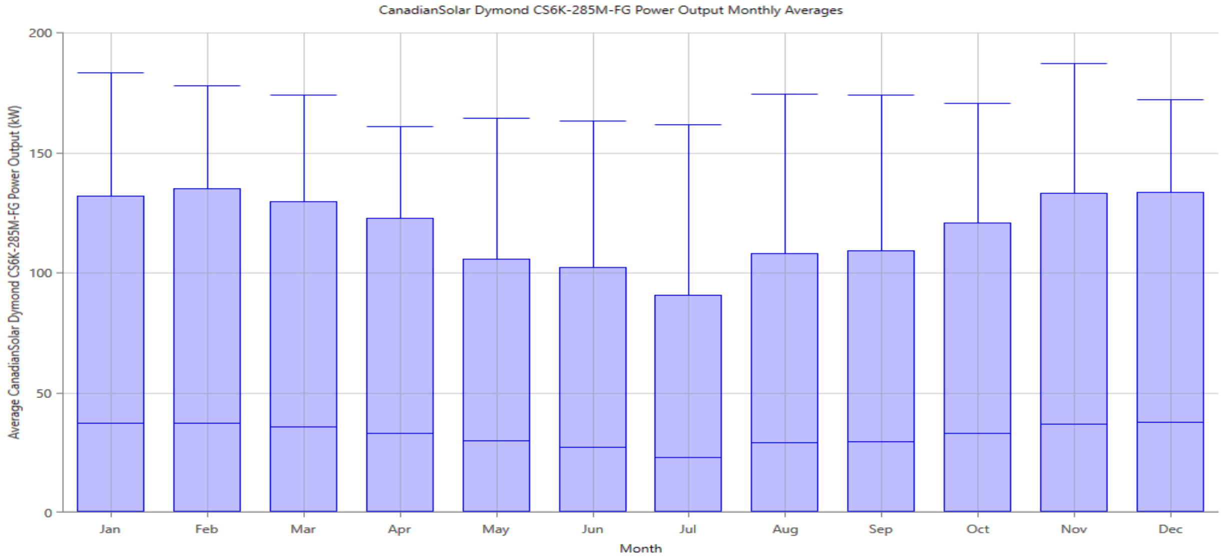

Figure 5: PV average monthly power output.

3.1.2 Natural Gas Generator Output

The generator used was a 200kw natural gas powered. On simulation, the generator produced 356,771kWh of energy per year with a peak supply of 160kW and a mean output of 56.7kW. The figure 6 revealed that the generator operated for a longer period of time during which it used up to 103,464m^3 of natural gas annually. The energy supplied by the generator accounts for about 55% of the total energy demanded by the community over a period of one year.

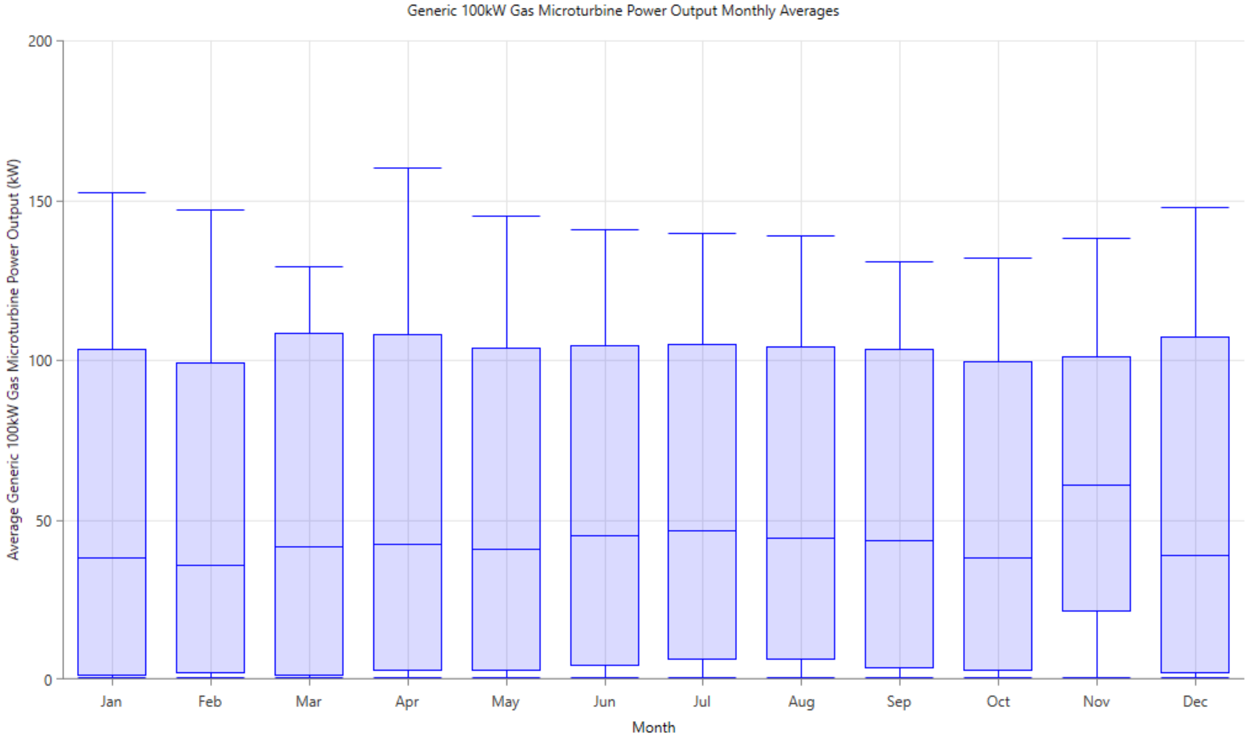

Figure 6: Power Output Monthly Average of the Natural Gas Generator.

3.1.3 Optimal Average Electric Production

Figure 7 showed an equitable share of energy contribution between the generating units as the NGG produces about 55.7% whereas PV system produces 44.3% of the total power utilization of the community for simulation. The proposed hybrid system produced a total of 640,207kWh of energy per year while the primary load demand over the year was 626,834kWh/yr. Therefore, a 0.29% in excess energy generation was observed amounting to about 1,862kWh/yr which is approximately 5kWh/day. The proposed system showed zero unmet loads and zero capacity shortage throughout the simulation period.

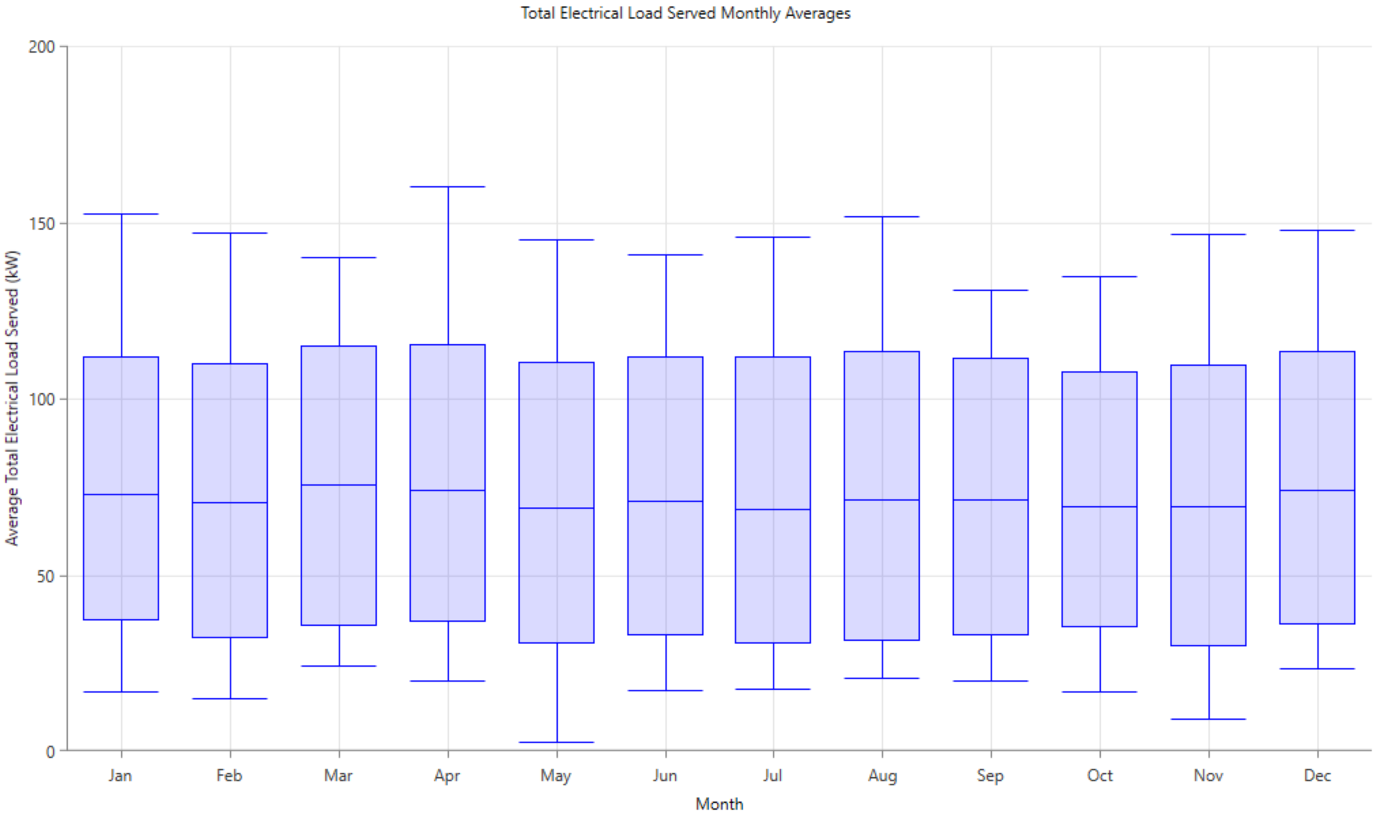

Figure 7: Average Electrical Load Served.

3.2 Economic Metric and Simple Payback Period

In Nigeria, the current energy cost of Band A subscribers fluctuates between $0.129-0.132 per kWh which fluctuates between N219.3-224.4 per kWh at N1,700 per $1 rate. Even with this new adjustment in the tariffs to completely deregulate the electricity sector, the consumers still do not enjoy reliable and efficient power delivery. The same Band A consumers still relies on their conventional fossil fuel powered alternatives to make up the difference on a daily basis. Therefore, adding this will further increase the overall COE of the user.

Whereas the proposed system delivered an energy cost of about $0.0394 per kWh showing a significantly cheaper solution compared to the existing system of operation from the user perspective. The COE indicates the minimum cost of producing a kWh of energy before transmission to the end user. The proposed system model produced a COE of $0.0394 per kWh which will be about N66.98 per kWh of energy which is significantly much lower than the existing rate even after other fixed rate will added to absorb the administrative overhead cost. This showed an improved margin of over 300% that provides an adequate allowance to accommodate other fixed costs and administrative costs in running the system. Therefore, the final COE payable by the users will be cheaper than what is currently obtainable. The TNPC tells the investor about the financial implication of the project over the project life cycle as compare to the site potentials. The ROI is positive at 7.8 per and the simple payback period at 7.48 years with the optimized COE. This indicates that the proposed hybrid configuration was both viable and profitable for a community-based application of this nature.

3.3 Emission Analysis of the Hybrid System

Natural gas is known to produce less carbon dioxide thereby significantly enhances the reduction of carbon footprint, and GHG emissions and by extension contributing to global warming mitigation. Nigeria sits on one of the largest natural gas deposits and will dynamically give a renew focus in the electricity generation section especially on the micro-modular units. Annually, the proposed hybrid system produces 199,755kg/yr of carbon dioxide, 664kg/yr of carbon monoxide, 1,394kg/yr of nitrogen oxide, and 18.7kg/yr of particulate matter. This is a significant reduction compared to the volume produced by the community using a diesel-powered generator in a conventional setup with the epileptic national grid supply. Diversion to utilizing natural gas as a major source of energy derivation will ultimately reduce gas flaring in the upper-stream sector of the oil and gas industry and further reduce the dependency on the diesel counterpart that releases large pollutants. This shift will reduce the country's carbon footprint and GHG annual index and improve the affected region's environmental condition, especially the coastlines.

4.0. Conclusion

This study was done to provide a feasible insight into the application of a hybrid system with microturbine gas generators with RES to deliver sustainable power to the growing community of HELIU residents in the Enugu State of Nigeria. Since electricity distribution designs are based on site location, generation source utilization, demand potential, and environmental impact, numerous works have tried to propose and design energy models for different locations and purposes. From the rural community academic proposed designs through donated power equipment to an actual community-enable off-grid system, these works concentrated majorly on the well-known conventional energy resource integrated with PV, Wind, or Biomass. Non-considered the use of Natural Gas as an alternative to Diesel in an Off-grid system or grid-tied. The key component rates were based on international pricing which is very much different from local reality while considering inflation and foreign exchange volatility. The energy demand profile of the case study of most of the reviewed works was based on the estimated load consumption of individual household appliances, not on the actual power consumption data. This study explores a scalable solution in the development of an optimal Hybrid Renewable Power System (HRPS) towards a sustainable power supply to the growing community of Heliu Residency in Enugu State, Nigeria. And further emphasis was focused on the integration of Solar photovoltaic (PV) modules, energy storage units (ESU), and small natural gas power plants (SNGPP). The research took into consideration the average and peak energy demand of the estate while analyzing the demand behavior. As a result of the deregulation of the power industry, tariffs have risen by over 200% driving energy consumers to seek affordable energy solutions. Considering that the power industry of the nation is plagued by epileptic, unstable power supply, users have been using diesel generators or premium motor spirit (PMS) powered generators to augment the large shortages from the national carrier. Also, the current complete deregulation of the downstream sector of the oil industry saw over 600% increase in the price of PMS making it difficult for the populace to sustain the conventional alternatives. RES provides a cheaper alternative as the energy source is naturally available and the conversion component has become even more affordable over the years. The proposed HRPS was designed and simulated using Homer software. The design was optimized to meet the community electrical load demand while reducing COE, AOC, fuel consumption, and emission. The existing energy configuration was used as a base case on the economic parameter, especially the COE. Currently, the base case produced a COE of $0.132 per kWh, which was the national grid supply cost without including the cost of running the diesel/PMS-powered alternatives. Homer optimized the proposed system component size for the selected PV/NGG/BESS configuration to be 200kW/200kW/700kWh. The base case, being the national power grid yielded a COE of $0.1/kWh. In comparison, the optimized HRPS configuration (200kW PV, 200kW SNGPP, 700Kwh ESS) achieved a COE of $0.0394/kWh about N66.98 at N1,700 per $1, with an initial capital cost (ICC) of $151,500 about N257million per $1, an AOC of $24,610 about N42million per annum and a total net present cost (TNPC) of $32,998,500. The proposed system showed zero unmet loads, zero capacity shortage, and a 5kWh/day excess energy with a renewable penetration fraction of 43.1%. The proposed system showed an improved performance considering the key metrics as compared to the base case economically, further enhancing sustainability and scalability. This showed an improved margin in cost of energy with over 300% that provides an adequate allowance to accommodate other fixed costs and administrative costs in running the system. Therefore, the final COE payable by the users will be cheaper than what is currently obtainable. Furthermore, the annually GHG emission of the proposed hybrid system produces 199,755kg/yr of carbon dioxide, 664kg/yr of carbon monoxide, 1,394kg/yr of nitrogen oxide, and 18.7kg/yr of particulate matter. This is a significant reduction compared to the volume produced by the community using a diesel-powered generator in a conventional setup with the epileptic national grid supply. This will greatly improve the quality of life of the community residents. Compared to the base case scenario, the proposed system had an economically and environmentally superior performance with improved reliability, use comfort, and sustainability, and is easily scalable.

5.0 Recommendation

Further works should consider the impact of the projected cost developing this project to the COE, AOC and TNPC.

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