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Hybrid Energy Systems: Optimal Resource Determination and Cost Evaluation Using Homer Grid Software

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Abstract
This paper proposes a resource evaluation and validation study of a grid-connected hybrid power system which tends to maximize the use of renewable energy generation with energy storage systems while minimizing the total system cost. The HOMER (Hybrid Optimization of Multiple Energy Resources) Grid software is adopted in this study to find the optimal configuration of solar energy sources with battery storage systems to deliver complementary electricity supply to satisfy AC primary load of 68.55 kWh/day with a 10.2 kW peak load demand to a building on a University campus premises located in the Niger Delta region of Nigeria. The results obtained from simulations showed a list of feasible resource configurations for the hybrid system. However, the most optimal/economical configuration is a grid-connected Solar PV-Gasoline system with a least cost of energy (COE) at ₦93.83/kWh and 6.7% renewable energy fraction.

Keywords: Electricity, DG, HOMER Grid Software, Renewable Energy, Optimization, Solar PV

1. Introduction

Presently, Nigeria is bedeviled by acute electricity supply crisis. There are severe power delivery deficits and acute power quality issues to consumers connected to the grid. The traditional method of using only the central grid system for electricity supply is not meeting the energy needs of the average Nigerian, as only 40% of the population is connected to the utility grid while power supply difficulties are experienced around 60% of the time [1]. Recently, the new paradigm is to engage the use of Distributed Generation (DG) comprising renewable energy sources. When two or more renewable sources such as wind, solar, biomass etc. coupled with energy storage components, such as batteries and gas/diesel engines as backup are used in providing increased system efficiency and greater balance in electrical energy supply, then we have a hybrid energy system [2-4]. Such systems can be greatly used in mitigating electricity supply problems in the light of current realities.

Several methods and works have been done on hybrid power systems as seen in Okedu and Uhunmwangho [5] who investigated the energy efficiency of renewable energy system consisting of a PV, three batteries, isolated AC diesel generator and a converter system using HOMER to calculate the best option that would give the best energy efficiency. Prasetyaningsari *s*. [6] designed a system to support the electricity demand of fish pond areation system by applying simple approach for sizing electricity system using HOMER to fulfil the requirement of 450 Wh/day primary load with 1.692 Wh/day peak load. The result showed the optimal sizing of photovoltage 1 kW, 8 battery of 200 Ah and inverter 0.2 kW, the most economically feasible and least cost of energy (COE) was about 0.769 $/kWh. According to Sigarchian *et al*. [7] a hybrid energy system for providing electricity and drinkable water for 1000 persons in disaster situations using a Transient Simulation System (TRNSYS) program was designed. The resultant model was significantly in choosing the right size of the different components and mitigating environmental issues compared to using only diesel engine that was previously a common solution in such disaster situations. Also, Singh *et al*. [8] in their work did computation, simulation and optimization of a hybrid energy system using HOMER Pro 3.2.3 for an educational institute. The analysis of the hybrid energy systems feeding AC primary load of 101 kWh/day energy consumption with a 5 kW maximum load demand and the simulation results showed the optimized size of components, biomass gasifier (5 kW) – Solar (5 kW) – fuel cell (5 kW) and optimized cost of energy of about 15.064 Rs/kWh.

Work done by Wondwossen and Chandrasekar [9] successfully designed a micro-grid system used to supply a reliable and cost effective electric power for a rural village using HOMER Pro software. The design was done by considering the present daily load profiles and future load forecast. Naorem *et al*. [10] analysed the sizing of PV system installation in a selected location for optimal operation using Homer software. The main objective was to reduce the total net present cost (NPC) and the sizing of the system. Zahboune *et al*. [11] presented a method for desiging hybrid electricity generation systems based on the Modified Electric System Cascade Analysis Method. The results from MESC Analysis and Homer Pro showed that both tools successfully identified the optimal solution with difference of 0.04% in produced energy, 5.4% in potential excess of electricity and 0.07% in the cost of the energy. Brandoni and Bošnjakovic [12] in their work assessed the benefits of integrating renewable energy technologies to satisfy the energy need of a

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wasterwater treament fa1cility based on conventional activated sludge system. Using HOMER, they demonstrated that using the obtained optimal configuration of a hybrid system (constituting of PVs, wind turbines and internal combustion engines) 33–55% of the energy demand of a wastewater facility located in Sub-Saharan Africa can be addressed, while the COE is lower than the local cost of electricity. In another study, Rinaldi *et al*. [13] determined the optimal sizing of the hybrid renewable energy systems for rural electrification in Peru. Results showed that the optimal configurations obtained can be utilized as guideline for designing electrification systems (with a minimized cost) for the considered communities and other villages with similar characteristics. Nallapaneni *et al*. [14] proposed a hybrid renewable energy microgrid (HREM) and its optimization for a remote community in South India. Results from the investigation which dealt with the optimum sizes of the different components used showed that the HREM would provide energy access to households that are affordable, reliable, sustainable, and modern. Marneni *et al*. [15] analyzed and simulated a practical rural feeder of 3.06 MW peak load in Mysuru, Karnataka, India using Power World Simulator (PWS). Also, HOMER was used to find the optimal sizing of solar photovoltaic generation to enhance the voltage profile of the feeder. Lastly, Alsharif [16] in his work obtained using HOMER software the optimal configuration of PV and battery system for heterogeneous cellular networks. Results showed that the deployment of the solar power system to be an energy efficient and cost-effective alternative for supplying heterogeneous cellular networks.

The main objective of this study is to design and conduct performance analysis of a grid-connected hybrid power system using HOMER Grid software and compare an experimental setup with simulation results to validate the potentials of solar PV resource as a complementary supply agent for cost effective hybrid system. The research is an effort to ensure proper development and deployment of hybrid energy system to any premises especially in Effurun-Warri City in the Niger Delta region of Nigeria.

2. Materials and Methods

This work entails determining the optimal resource and cost of PV system installation located at the Electrical and Electronic Engineering Departmental Building of the Federal University of Petroleum Resources, Effurun (5º33.4'N, 5º48.3'E) using HOMER Grid software. Figure 2.1 shows the block diagram of the proposed grid-connected hybrid system model. A grid-connected mode of operation is considered such that the main grid is used as the backup power system. The aim is to reduce the total net present cost (TNPC), levelized cost of energy (LCOE) and the sizing of the system. The considered components are PV arrays, Battery energy storage systems, gasoline/petrol generator and a Converter. The average daily load data at the case study location, monthly temperature and solar irradiance data were collected and used as inputs for the analysis. Table 2.1 shows the average daily load data obtained from the building. The performance analysis of the grid-connected hybrid power system using HOMER Grid software will be compared to experimental setup with simulation results to give the optimal size and costs of the system.

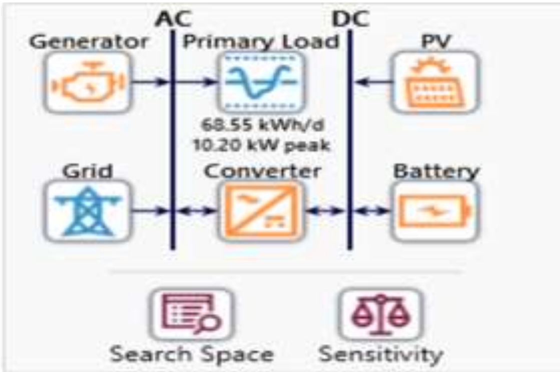

Figure 2.1: Schematic Diagram of Hybrid System

Table 2.1: Average Daily Load Data at the Case Study Location

Items	Quantity	Power (kW)	Total Power (kW)
Staff Office and Electronics Laboratory LED Lighting	150	0.005	0.75
Outside LED Lighting	50	0.025	1.25
Electric Ceiling Fan	30	0.200	6.00
Office Computer Laptop	20	0.075	1.50
Office Photocopier Machine	1	0.250	0.25
Office Laser Jet Printer	1	0.250	0.25
Electronics Laboratory Experiment Modules	10	0.020	0.20
Total			**10.20**

2.1 Hardware Design (Experimental Setup)

2.1.1 Choice of Solar PV Array

Figure 2.2 shows the solar irradiation map of the Niger Delta region in Nigeria [17] where irradiation is less than 1,750 kWh/m^2, recording the lowest values in the country's solar map. This low irradiation in the region is partly due to the geographical location of the area and the prevalent rainy climatic condition of the region. Therefore, apart from the design calculations for solar PV installation requirement for this area, it is important to properly investigate the real output behavior of installed PV to help determine solar power that will be generated.

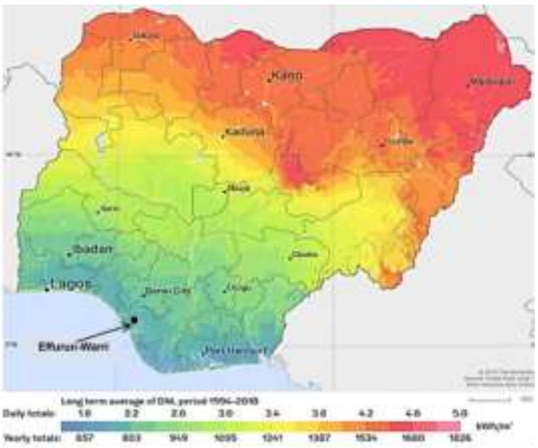

Figure 2.2: Solar Irradiation Map of Nigeria [17]

To determine solar power variations in the proposed site, a solar array of 2.4 kWp test bed was set up at the Electrical and Electronic Engineering Department building of the Federal University of Petroleum, Effurun as shown in Figure 2.4. Daily data were acquired from the setup at hourly intervals with various data acquisition instruments (Infrared thermometer, pyrometer and clamp meter). Parameters measured include solar irradiation, solar panel temperature, PV output voltages and currents. An average monthly data for the whole study year of 2019 are presented in Table 2.2.

2.1.2 Choice of System Assets

Gasoline generators are mainly used as backup to electricity supply from the main grid. In this study, a 3.5 kW capacity gasoline generator is used. However, due to its frequent on and off actions over a 24 h period to ensure reliable electricity supply, it has become very expensive to operate the gasoline generator as an alternate source of electricity supply to the case study area.

A 3.5 kW capacity bidirectional converter is used, that serves both as a rectifier and an inverter with a capital cost and replacement cost assumed to be ₦293,000 for a 25-year lifetime.

Four (4) numbers of Absorbed Glass Mat (AGM) batteries with 200 Ah capacity is used in the study to give the required backup during times of emergencies where supply deficits occur. The capital and replacement costs are assumed to be ₦800,000 for a 5-year lifetime.

2.1.3 Load Profile

Figure 2.3 shows the daily load profile for the month of January in the 2019 study year. The location recorded the highest load profile values in the month of January with an average load of 2.86 kW, Peak load of 10.2 kW, and a load factor of 0.28.

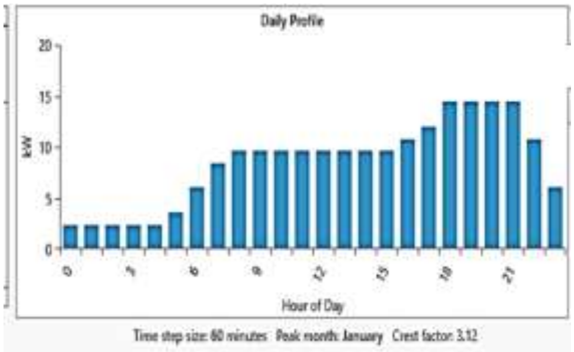

Figure 2.3: Daily Load Profile curve of the study location

The experimental setup at the location is presented in Figures 2.4 and 2.5. Also, the average monthly data obtained for the whole study year of 2019 are presented in Table 2.2 while the monthly average solar global horizontal Irradiance (GHI) data for the location is plotted in Figure 2.6.

Figure 2.4: Experimental Setup at the Location: 2.4 kWp Solar PV array

Figure 2.5: Experimental Setup at the Location: Inverting Unit, Storage Battery and Charge Controller Assembly

Table 2.2: Average Monthly Setup Solar PV System Data for the Year

Month	Cell Temperature (℃)	Irradiation(kWh/m^2/day)	Current (A)	Voltage(V)	Power (kW)
January	21.7800	1.7000	7.0700	30.8800	0.21832
February	22.1000	1.6500	7.4200	31.9800	0.23729
March	22.4000	1.4000	8.2200	30.9200	0.25416
April	22.5200	1.3500	7.6600	31.8800	0.24420
May	22.8800	1.2800	7.5200	30.8300	0.19967
June	23.6300	1.2300	6.8100	29.3200	0.19967
July	24.9000	1.2000	5.4200	27.4500	0.14878
August	26.7500	1.2500	5.3700	26.6700	0.14322
September	26.7500	1.2400	6.2900	28.5000	0.17927
October	30.3200	1.2560	7.9500	30.2400	0.24041
November	44.4200	1.3560	8.1900	30.8000	0.25225
December	50.2800	1.4670	7.8700	31.7100	0.24956

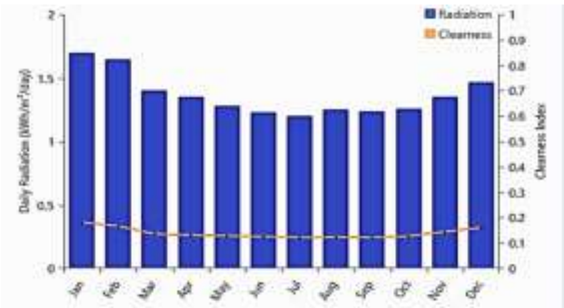

Figure 2.6: Monthly Average Solar Global Horizontal Irradiance (GHI) Data

2.2 Software Design

2.2.1 Simulation

Here, for the purpose of analysis, the considered components are PV arrays, Battery energy storage systems, and a Converter. In the process, an hourly energy balance calculation through a whole year was performed by HOMER Grid based on the system configuration comprising several numbers of component sizes. After simulation, it determines the best optimal system configuration which is suitable to meet the overall energy demand. HOMER Grid was used in simulating the designed system based on capital costs, estimation of installation costs, replacement costs, operation and maintenance costs, grid energy supply cost and interest rate.

2.2.2 Optimization

The optimal solution is obtained after simulating the entire possible number of selections of hybrid renewable energy system configuration. A list of configuration results is displayed in a sorted format considering Total Net Present Cost (TNPC) and Levelized Cost of Energy (LCOE). HOMER Grid analyses the different types of system configuration from the lowest to the highest TNPC and LCOE. However, the system configuration based on TNPC and LCOE is varied depending on the sensitivity variables that has been selected (in this study, solar insolation and fuel cost are the variables for the sensitivity analysis).

2.2.3 Sensitivity Analysis

The HOMER Grid software was used in performing the iterations to get optimal results for every selection including sensitivity variables for the hybrid renewable energy system. The sensitivity variables considered for this process are the average solar radiation and fuel cost. A list of the various system configurations of the designed hybrid renewable energy system is then presented in a tabular form considering a cost wise analysis i.e. lowest to the highest TNPC and LCOE. The optimal solution means a hybrid renewable energy system having the lowest TNPC and LCOE.

3. Results and Discussion

3.1 Optimization Result

Table 3.1 shows the optimization results obtained from the HOMER Grid software simulation of the hybrid energy system. The result shown explains four (4) out of hundreds of possible system configurations for the energy resources available for the project. The experimental setup for the study is represented as the base case comprising Solar PV panels, battery storage, gasoline generator, and the main grid. The result of the simulation obtained a Cost of Energy (COE) of ₦94.56/kWh and a renewable energy fraction of 6.7%. However, the first result in the table shows the configuration with all assets of the base case except battery storage devices as the most optimal system configuration with a COE of ₦93.83 and a renewable energy fraction of 6.7%. The gasoline-grid system configuration has a COE of ₦99.83 and a 0% renewable energy fraction. This implies higher carbon emissions over the period of study. The highest COE of ₦100.58 and a 0% renewable energy fraction is the gasoline-battery-grid system configuration. This will have the tendency to reduce carbon emissions, but with the highest operating cost because of the cost of large number of battery storages required for any CO_2 reduction over the study period.

Table 3.1: Optimization Results

Architecture					Cost		System	
PV (kW)	Generator (kW)	Battery	Grid	Converter (kW)	NPC (₦)	COE (₦)	Ren Frac (%)	CO_2 (kg/yr)
2.40	3.50		1	1.97	₦97.4M	₦93.83	6.70	14,754
2.40	3.50	2	1	2.04	₦98.2M	₦94.56	6.70	14,754
	3.50		1		₦104M	₦99.83	0	15,813
	3.50	2	1	0.146	₦104M	₦100.58	0	15,813

3.2 Sensitivity Analysis

The sensitivity variables chosen are cost of Gasoline/Petrol fuel Price and Solar Scaled Average Insolation. The selected sensitivity variables were used in the simulation as shown in Table 3.2. Varying generator fuel cost and solar irradiation, new results for cost of energy and renewable energy fraction were obtained. Two gasoline fuel prices are set to see how fuel cost affects the NPC and COE values with different solar insolation values for a grid connected PV-gasoline system. It can be seen from the results that increase in fuel costs do not have any effect on NPC and COE values. However, CO_2 emission increases with decreasing solar radiation values. At a fuel cost of ₦145 and solar radiation of 4.62 kWh/m^2, 14,128 metric tons of CO_2 emissions while at the same fuel cost and with 2.56 kWh/m^2 solar radiation, 14,754 metric tons of CO_2 were obtained for the simulation year.

Table 3.2: Sensitivity Analysis Results

Sensitivity		Architecture					Cost		System	
Gasoline Fuel Price (₦/L)	Solar Scaled Average (kWh/m^2/day)	PV (kW)	Generator (kW)	Battery	Grid	Converter (kW)	NPC (₦)	COE (₦)	Ren Frac (%)	CO_2 (kg/yr)
100	2.56	2.40	3.50		1	1.97	₦97.4M	₦93.83	6.70	14,754
100	2.62	2.40	3.50		1	1.97	₦97.3M	₦93.69	6.84	14,731
100	3.45	2.40	3.50		1	2.04	₦95.5M	₦91.95	8.59	14,455
100	4.62	2.40	3.50		1	2.19	₦93.3M	₦89.88	10.7	14,128
145	2.56	2.40	3.50		1	1.97	₦97.4M	₦93.83	6.70	14,754
145	2.62	2.40	3.50		1	1.97	₦97.3M	₦93.69	6.84	14,731
145	3.45	2.40	3.50		1	2.04	₦95.5M	₦91.95	8.59	14,455
145	4.62	2.40	3.50		1	2.19	₦93.3M	₦89.88	10.7	14,128
250	2.56	2.40	3.50		1	1.97	₦97.4M	₦93.83	6.70	14,754
250	2.62	2.40	3.50		1	1.97	₦97.3M	₦93.69	6.84	14,731
250	3.45	2.40	3.50		1	2.04	₦95.5M	₦91.95	8.59	14,455
250	4.62	2.40	3.50		1	2.19	₦93.3M	₦89.88	10.7	14,128
300	2.56	2.40	3.50		1	1.97	₦97.4M	₦93.83	6.70	14,754
300	2.62	2.40	3.50		1	1.97	₦97.3M	₦93.69	6.84	14,731
300	3.45	2.40	3.50		1	2.04	₦95.5M	₦91.95	8.59	14,455
300	4.62	2.40	3.50		1	2.19	₦93.3M	₦89.88	10.7	14,128

3.3 Comparison and Validation Analysis

The experimental set up for this study is the exact base case configuration for the HOMER Grid simulation result in terms of the total operating cost over the study period and the initial capital for the setup. The months of January and July are where the highest demand and lowest demand occurred, respectively. With the categorized simulation results shown in Table 3.1, the monthly electrical bill breakdown for the configurations with and without solar PV generation assets is as shown in Figures 3.1 to 3.4, respectively. The categorized configuration represents two sets of configuration types: (1) Hybrid system with Solar PV connection, and (2) Hybrid system without Solar PV connection. Lastly, Figure 3.5 shows an overview of utility bill for categorized configurations which indicates a higher total energy cost for systems without solar PV renewable energy assets.

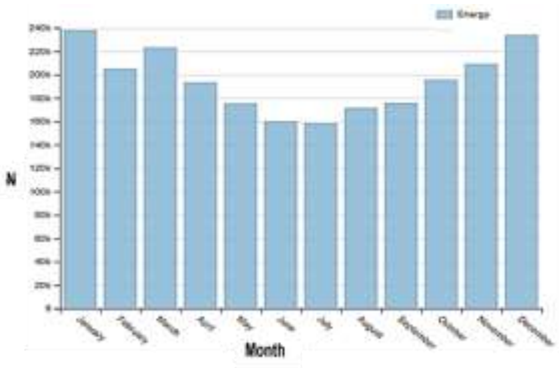

Figure 3.1: Monthly Electrical Bill Breakdown for: Solar PV + Generator + Grid Configuration

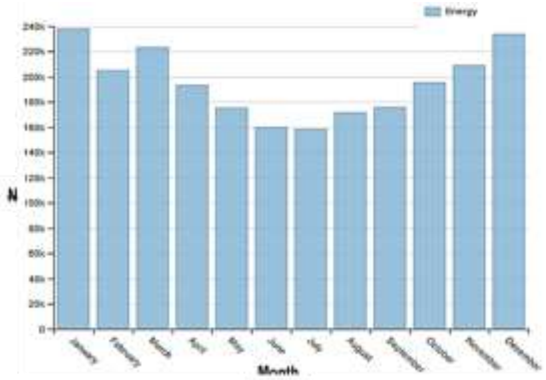

Figure 3.2: Monthly Electrical Bill Breakdown for: Solar PV + Generator + Battery + Grid (Base Case) Configuration

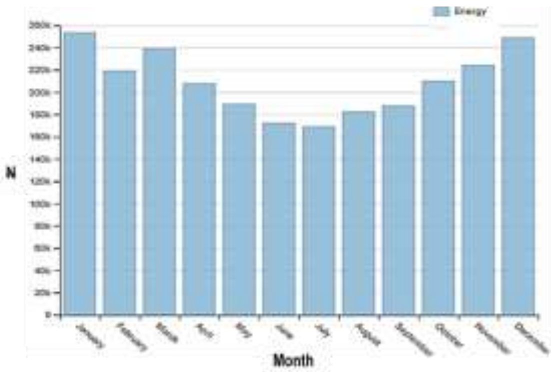

Figure 3.3: Monthly Electrical Bill Breakdown for: Generator + Battery + Grid Configuration

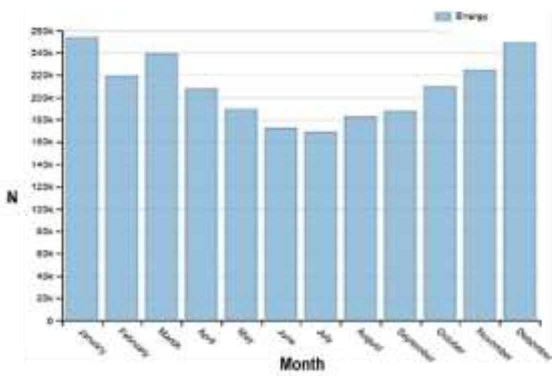

Figure 3.4: Monthly Electrical Bill Breakdown for: Generator + Grid Configuration,

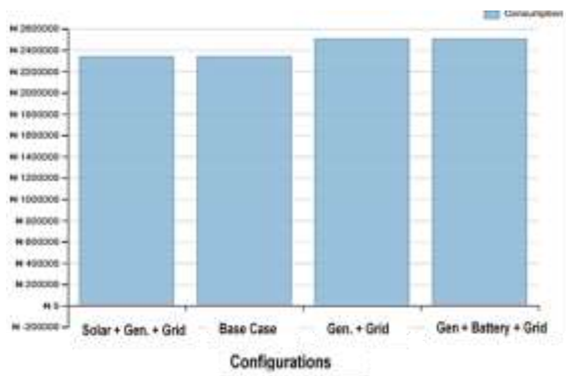

Figure 3.5: Utility Bill Overview for Categorized Configurations.

4. Conclusion

A comparison between the hybrid systems with and without solar PV connections has shown a significant amount of savings that can be achieved by the deployment of renewable energy as an alternative electrical source for the AC loads at the study location on a yearly basis. In the overview, the hybrid system without solar PV connections incurred cost of ₦2.5M as compared to ₦2.3M for hybrid systems with solar PV connections on utility bills. It could be clearly observed that the battery storage systems have less significant impact on total utility bills as of the case of solar PV systems. The investigation of the grid connected hybrid solar PV-gasoline-battery system in the proposed site clearly indicates that it has the potential of delivering the required power demands economically and ensure reliable electricity supply to loads just as the optimal system configuration comprising solar PV, gasoline and grid connected obtained in the HOMER Grid simulation software without any battery storage. Both hybrid systems have the same monthly electricity bill breakdown costs. However, the base case configuration has a higher NPC and COE due to the very high cost of energy storage systems. Also, the simulation has shown an optimal resource configuration without energy storage systems in place and having the least system cost. The optimal and the base case system configuration comprising renewable energy assets, have lower CO_2 emission of 14,754 metric tons as compared to other systems without renewable energy production assets that incurred higher CO_2 emissions of 15,813 metric tons. Hence, less negative environmental impact in terms of pollution due to less carbon emissions will be attained with the optimal and base case system configurations because of the presence of renewable energy sources. Future research to further investigate wind and biogas resource potentials at the study location will be carried out.

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