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Analysis of Multi-Distributed Generation Systems Based on Solar/Biomass/Natural Gas/Diesel Energy Resources for Off-Grid Application

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Abstract
This study presents the analysis of multi-distributed generation systems for 20 off-grid homes in Ogun State based on the techno-environmental analysis planning (TEAP) approach. The technical aspect includes the load, DG capacities, energy generation/year, and the unmet energy demand (UED. The paper considers and compares different energy configurations such as the PV-based DG, the hybrid DGs: PV/biogas, PV/biogas/natural gas, PV/biogas/diesel, PV/diesel, and the diesel-based DGs. The environmental aspect examines the emissions produced by the DGs compared to a diesel-based DG system. The paper also examines the effect of temperature on the performance of the PV system. The simulation is based on a total daily demand of 99.04 kWh/d, and the solar, ambient temperature and the biomass data in Hybrid Optimization of Multiple Energy Resources (HOMER) environment. The size of the PV-based DG obtained is 36.9 kW, which generates 54,565 kWh/yr without temperature effect. Result shows that this value reduced to 48,268 kWh/yr with temperature effect and the value of UED is 7.84 %. The biogas, natural gas and diesel generators have the same size of 13.2 kW. The hybrid DGs achieve a UED of 0% implying 100 % system availability. Results further demonstrate that the mentioned hybrid DGs have CO_2 emissions that range between 2.21 and 15, 448 kg/yr, compared to a value of 40, 273 kg/yr obtained when the homes are entirely run on a diesel-based DG. The study can help to understand energy systems analysis.

Keywords: Biogas, Distributed generation, Emission, Renewable energy, Natural gas

1.0 INTRODUCTION

Existing scholarly works have shown that a lack of access to electricity supply is among the problems encountered by several energy-poor communities around the globe, including those in Nigeria [1, 2]; this development greatly affects their productivity, social and economic lives. This continues to motivate research studies that proffer eco-friendly solutions to energy poverty within the rural communities.

Renewable energies are identified as means to addressing the problem of energy shortage and poverty [3, 4]. By this, communities can harness the natural and eco-friendly resources available to them to address the energy supply problem. The quantity of sawdust generated from sawmills in several communities in Nigeria, for instance, continues to increase due to increase in timber/lumber production to meet a growing demand for wood products.

Unfortunately, the country does not have the capability for recycling waste materials, which is why sawdust heaps are wrongly considered a waste and are then burned, thereby contributing to greenhouse gas (GHG) emissions, while some quantity of sawdust is also conveyed into rivers and this results in pollution of water bodies [5]. These are part of the justifications for effective management of natural resources that can be useful for generating clean and eco-friendly electricity supply according to the United Nation's Sustainable Development Goals (SDGs) [6].

Furthermore, rather than waiting for a long time for the grid supply to be extended to the isolated communities, distributed generation (DG) may be sited close to the users to meet their energy demand [7]. DG can help to reduce

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power loss since the energy transport is close to the intended users, and can also minimize emissions especially when it is being fueled by a renewable energy (RE) resource [6, 8 - 9]. This implies that the design considerations are not only based on the technical dimension, but also include the economic, environmental, social and policy aspects [10]. This study considers the technical and the environmental analyses in a manner that it examines different fuels and technologies such as solar, biomass, natural gas and diesel systems.

Severally scholarly works were reported in the literature that considered different aspects of DGs for off-grid applications. It is of interest to mention some of these papers to create relevant background for the multi-DG systems that this current paper is based upon. A study was reported on the energy efficiency measures and hybrid PV/biomass power generation system, using the Moroccan city of Fez as case study [11]. The authors introduced an integrated analysis technique to improve the economic and environmental sustainability of the rural households, including an optimization strategy for the cost and energy analyses. An optimum techno-economic (TE) sizing of a solar/biomass microgrid with battery system was discussed using India as a test case [12]. The study employed an approach of mixed integer linear programming-based optimization in an attempt to determine the optimal sizes of the renewable energy-based microgrid.

A TE analysis of the hybrid application of biomass gasifiers and PV resources was discussed to satisfy the energy needs in Bangladesh's northern rural region [13]. The authors employed HOMER software to obtain different sizes of the generating systems. An optimization approach was proposed under uncertainty of a biomass-integrated RE-microgrid with storage [14]. The authors presented deterministic-based optimization and stochastic optimization techniques to analyze the technical and economic aspects.

A study also examined biomass in the electricity system [15]. The biomass was considered as a complement to variable renewable energy resources. The paper presents the analysis of biomass, wind and solar energy technologies. Hussain et al. [16] presented a comparative study on hybridizing systems with solar heat, biomass and thermal storage for energy production in Spain based on TE simulation and analysis. A TE analysis of wind/PV/biomass DG system was also presented for a local province in Pakistan using HOMER Pro software [17].

A TE evaluation of grid-integrated PV/biomass system for rice mills in Tripura, India was discussed [18]. The study presented a grid-connected hybrid system including grid, solar and biomass system to determine the most feasible option in terms of cost. The energy analysis and TE evaluation of PV/hydrokinetic-turbines/ battery/biomass gasifier hybrid system was designed using southern Ecuador as a case study [19]. The authors presented optimal energy configurations using sensitivity analysis. A TE assessment was presented for biomass gasification-based mini-grid system for efficient energy applications using the rural India as test case [20]. The authors modeled different energy systems in HOMER Pro environment. The optimization of an off-grid PV/biomass DG with different battery systems was presented [21]. The authors employed different optimization approaches such as the Flower Pollination, Harmony Search, Artificial Bee Colony and the Firefly algorithms to determine an optimal system capacity, using Monshaet Taher village in Egypt as case study.

A feasibility study of the Kudura hybrid generation system was presented using a small-scale PV-biomass and PV-diesel systems as test cases in Mozambique [22]. The authors presented a TE analysis of a solar photovoltaic-biomass gasification hybrid system compared to a diesel-based system. The optimal sizing of a biomass-based DG was discussed based on gasifier, solar PV, and a battery bank using TE analysis approach [23]. Similar existing studies have also been reported in [24-37] which are based on TE analysis approach for DG systems, most of which considered renewable energy and conventional resources and performance analyses.

These studies have made useful contributions to knowledge in different directions. The majority of studies presented in [11-37] considered detailed TE analyses but they did not consider the environmental performance aspect of integrating biomass with other non-conventional resources, while only a few publications discuss the environmental aspect. This current paper considers the design of multi-distributed generation (multi-DG) systems based on different resources such as solar, biomass, natural gas and diesel. The system design is based on a techno-environmental analysis planning (TEAP) approach, while the simulation is achieved by using a micropower optimization modeling tool (HOMER).

The technical aspect considers the load requirements, capacities of DGs, different configurations, energy generation per year, and the system reliability, while the environmental aspect considers the emissions produced or saved by different DG systems compared to a diesel-based DG. The emissions considered are carbon monoxide, carbon dioxide, unburned hydrocarbon, particulate matter, sulfur dioxide and nitrogen oxides. The paper considers the possibility of harnessing waste materials such as saw dust available in local communities in Ogun State Nigeria for energy generation.

2.0 METHODOLOGY

The proposed multi-DG systems are simulated in HOMER environment [38]. The tool provides the opportunity to take relevant input parameters and then produce results after running several simulations based on the configurations and the introduced fuels.

2.1 *Brief Description of Case Study*

The multi-DG systems are designed and analyzed using Agosasa location in Ogun State as a test case. This paper assumes the utilization of an agricultural resource - saw dust in particular. The monthly average solar irradiation and the ambient temperature data used for the simulation are shown in Figures 1 and 2 based on [38, 39]. The estimated biomass data, i.e., the quantity of sawdust from the sawmills in the location was based on [40]. The estimated biomass data assumed for the simulation is presented in Figure 3, which has been adapted from [40]. This has been obtained from parameters such as the amount of saw dust/day, total quantity of saw dust/yr, the number of sawmills in the state, number of working days in the year, and a multiplying factor because of seasonal variations.

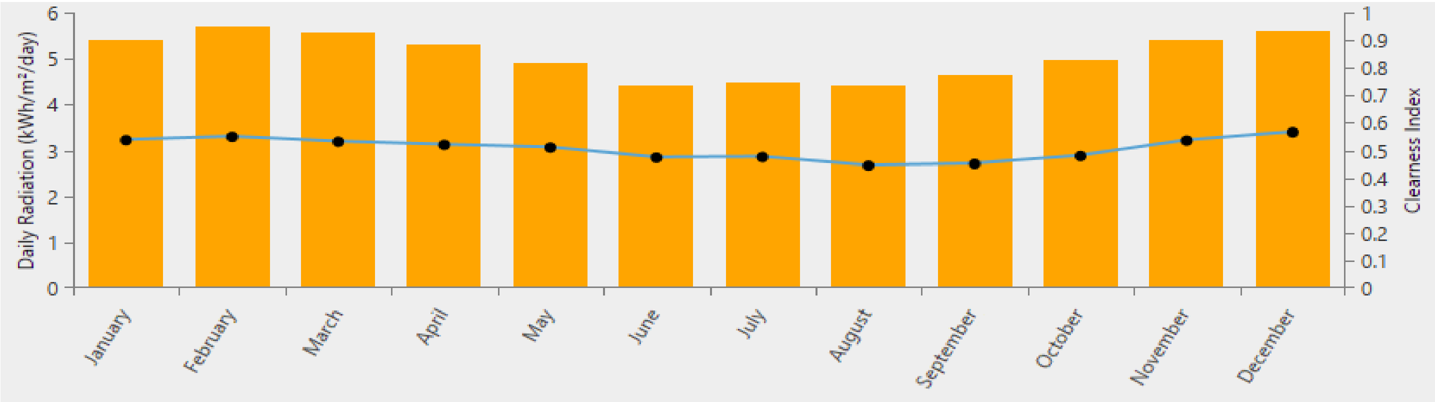


Figure 1: Solar radiation used for the simulation [38]

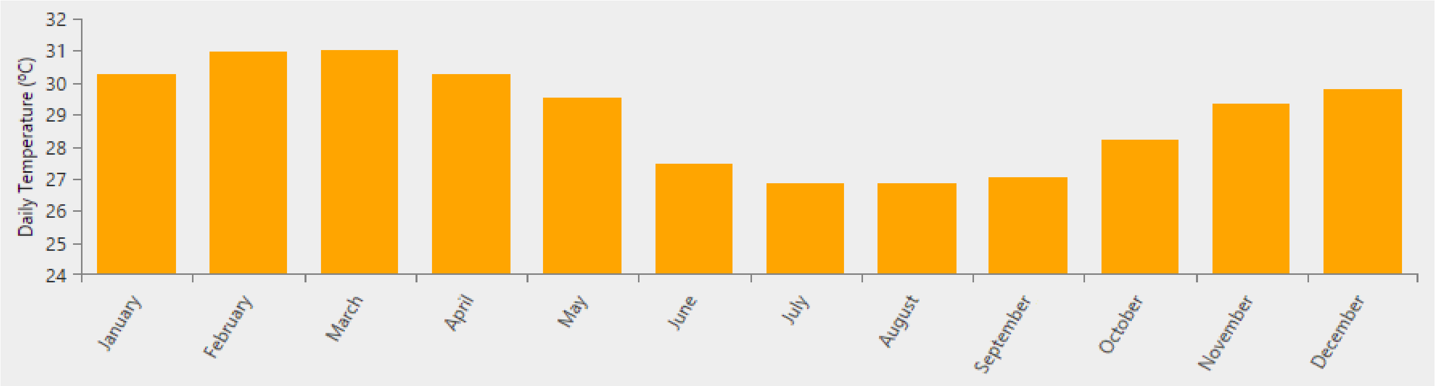


Figure 2: Ambient temperature used for the simulation [39]

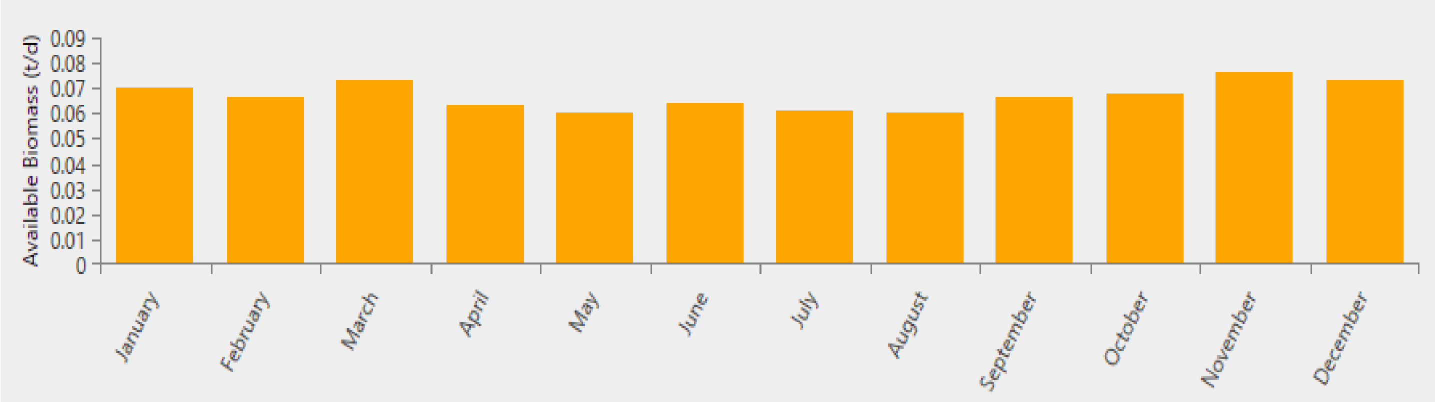


Figure 3: Sawdust data used for the simulation (adapted from [40])

Table 1. Users' load requirements

Load Type	Rated Power (W)	Quantity	Total Load (W)	Duration (hr)	Demand (1 home) (kWh/d)	Demand (20 homes) (kWh/d)
Lighting	18	8	144	8	1.152	23.04
Fan	75	2	150	8	1.2	24.00
Television	80	2	160	5	0.80	16.00
Radio	25	1	25	8	0.2	4.00
Refrigerator	200	1	200	8	1.6	32.00
					4.952	**99.040**

2.2 Load Demand Mode

The load demand of a particular appliance in an installation is given by Eq. (1) [38]:

$$E = n_a P_{rating}.t \tag{1}$$

where E is the energy demand (kWh); n_a is the number of appliances, P_{rating} represents the power rating of the appliance (kW); and t is the duration of operation of the appliances (hrs). Eq. (1) represents the energy demand of a particular type of appliance, but there are different types of appliances in the households such as lighting, fan, television, radio, and refrigerator. Eq. (2) represents the total demand by all the appliances, E_1 to E_n in the installation. The total daily demand assumed for 20 houses in this work is based on a field survey for a single home in Ogun State as presented in Table 1. The assumptions made is that all the homes consume the same energy for the purpose of analysis.

$$E_{total} = E_1 + E_2 + E_3 + E_4 + \cdots + E_n \tag{2}$$

2.3 Photovoltaic Array Sizing

The output power of a PV module can be calculated by Eqs. (3) and (4) [38, 43, 44]:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{G_T}{G_{STC}}\right) \left[1 + \alpha_P \left(T_C - T_{C,STC}\right)\right] \tag{3}$$

where Y_{PV} is the rating of the PV modules at STC; f_{PV} is the derating factor; G_{STC} is the solar radiation at STC; G_T is the solar radiation of the location; α_P is the temperature coefficient of power; $T_{c,STC}$ is the temperature of cell at STC, T_C is the cell temperature [38, 41-43]. T_C can be determined by Eq. (4) [45]:

$$T_C = T_a + (NOCT - 20).\left(\frac{G_T}{G_{REF}}\right) \tag{4}$$

where T_a, NOCT and G_{REF} are the location's ambient temperature, nominal cell operating temperature and reference irradiance. The values of G_T and G_{REF} are 1kW/m^2 and 0.8 kW/m^2. The values of NOCT, α_p and the solar PV module efficiency used in this work are 47°C, -0.5 %/°C and 13 %, respectively. The value of f_{PV} in this work is 80 %.

2.4 Charge Regulator Sizing

Regulating battery charging process is important to avoid the issue of over-charging. In practice, the charge regulator is usually over-rated say by 30% as presented in Eq. (5) so that it can accommodate over-current from the PV array [37, 45].

$$R_{size} = 1.3 \times I_{sc} \tag{5}$$

where R_{size} is the size of the charge regulator and I_{sc} is the short-circuit current (A).

2.5 Battery sizing

Eq. (6) can be used to calculate battery's energy storage capacity [43]:

$$C_{BAh} = \frac{E_{db} \times AD}{DOD \times \eta_{BAh} \times V_B} \tag{6}$$

where C_{BAh} represents the total ampere-hour; E_{db} is the daily energy requirements from the battery (kWh); DOD is the maximum depth of discharge; η_{BAh} is the battery's round trip efficiency; V_B is the voltage of the battery and AD is the days of autonomy.

2.6 DC-AC converter Sizing

PV systems produce DC, and this requires a conversion to AC to be able to run AC-based appliances. Determining the sizing of a DC-AC converter is affected by the kinds of loads present in the installation, such as resistive or inductive loads [24]. The size of a DC-AC converter can be calculated using Eq. (7) [45]:

$$Inv_{size} = 3 \times (L_i) + (L_{others}) \tag{7}$$

where Inv_{size} is the inverter capacity (kVA); L_i represents the inductive load (kW); L_{others} is the other load (kW).

2.7 Biomass Gasifier

In biomass gasification technology, solid bio-residue is converted into a gaseous fuel, which is then used to generate electrical energy [46, 47]. Eq. (8) can be used to determine yearly electricity (E_{bmg}) generated by a biomass gasifier [46, 48].

$$E_{bmg} = P_{bmg}\,(8760 * CUF) \tag{8}$$

where P_{bmg} represents the system rating for biomass gasifier while CUF is the capacity utilization factor with 8760 being the number of hours in a year. In biomass systems also, parameters such as the calorific value, biomass availability (ton/yr.), and biomass gasifier usage hours are important design specifications. The mathematical relation for determining the maximum capacity of a biomass gasifier in a particular location may be also be found in [46, 48].

2.8 Estimation of annual sawdust production capability

To calculate the total amount of sawdust produced in a year in a particular sawmill, information such as the number of wood logs converted in a sawmill on a daily basis, the average log conversion rate, and the log characteristics which include the weight, girth diameter, and density are needed, including the factor of 312 [40]. The annual quantity of sawdust may be obtained using Eq. (9) [40]:

$$T_A = \left(\frac{V_L * \rho * N_L * C_A * N_{SM} * 312}{1000}\right) \tag{9}$$

where T_A represents the amount of sawdust (ton/year); V_L is the volume of one log (m^3); ρ is the wood density (kg/m^3); N_L is the average of the number of logs converted in a sawmill per day; C_A *is the* rate of log conversion; N_{SM} is the number of sawmills in the region. The number of working days in the year is 312. Eq. (10) was used to estimate the volume of one log [40]:

$$V_L = \pi \frac{D^2{}_g L}{4} \tag{10}$$

where D is the girth diameter (m) and L is the length of one log (m).

2.9 Generator sizing

Engine generators are usually configured to support the peak load in a given application. The rating of the generator is usually maintained at 20 % more than the peak load. The fuel consumption rate of the engine generator system can be estimated by Eq. (11) [38]:

$$F_c = X_1 P_{out} + X_2 P_{rated} \tag{11}$$

where F_c, P_{out}, P_{rated} , X_1 and X_2 are fuel consumption rate (litre per kWh), operating output power (kW), rated generator power (kW), generator fuel curve slope (typical value = 0.246 litre/kWh) and the fuel curve intercept coefficient (typical value = 0.08415 litre/kWh)

3.0 RESULTS AND DISCUSSION

3.1 Technical evaluation of the multi-DGs

3.1.1 Energy utilization profile

The users' load profile is shown in Figure 4, which has been obtained by adjusting the existing profile in HOMER to the daily consumption of the 20 homes [38]. The demand is 99.04 kWh/day, while the peak and the lowest load are 10.552 kW and 0.848 kW, respectively. As it can be observed from Figure 4, the minimum load occurs for the first 5 hours in the morning, when the users are asleep. The energy consumption increases in the morning when they wake up, and is almost fairly constant in the afternoon. The load demand starts increasing again at around 3 p.m. till around 10 p.m. in the evening when the demand began to decrease.

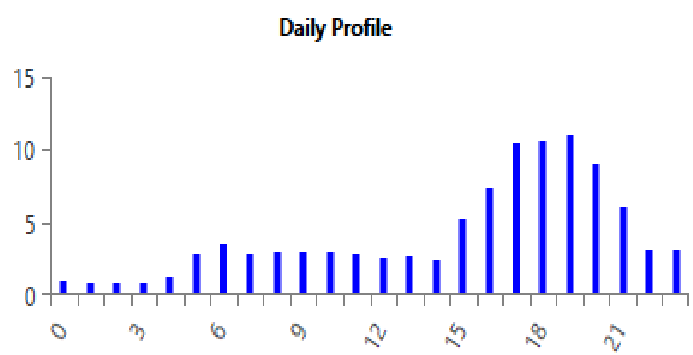


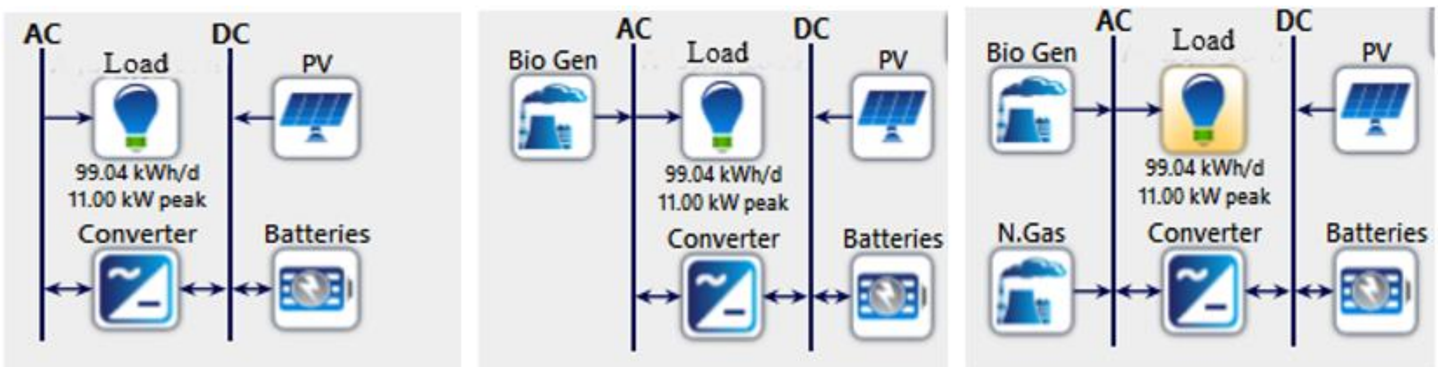
Figure 4: Load profile for the simulation

3.1.2 Size and output of PV-based DG

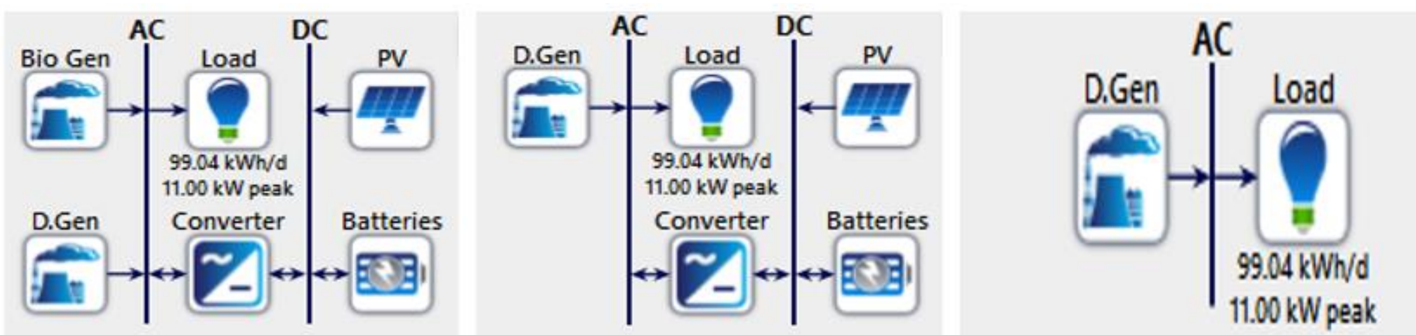
The DG system configurations are shown in Figure 5. The design in Figure 5 (a) is the PV-based DG, which consists of the PV, battery and converter. The size of the PV system is 36.9 kW. Without considering the effect of temperature, this PV-based DG produced 54,565 kWh/yr of electricity. However, it generated 48,268 kWh/yr of electricity when the effect of temperature is considered. The temperature effect leads to 11.54 % reduction in energy generation. The value of UED is 7.84 % (2,834 kWh/yr), signifying that a higher PV size will be needed to reduce the unmet load.

A 45 kW PV system was simulated, which delivers 58,863 kWh/yr of energy with a UED of 7.77 % (2,807 kWh/yr). A 60 kW PV capacity produced 78,484 kWh/yr of energy with a UED of 6.45 % (2,332 kWh/yr). Furthermore, with 70- and 80-kW PV-based DG systems, UED values are 6.32 and 5.56 %, respectively. The 45, 60, 70 and 80 kW systems were simulated with temperature effect, and the results demonstrate that UED reduces as the PV-based DG size is being increased. The monthly electric production for the 36.9 kW PV system is showed in Figure 6. It is also obvious that the energy generation from this system follows the solar irradiation profile of the location.

Supposed that 250 W SUNTECH PV module is selected, the controller capacity for the module will be rated 11.219 A since the module short-circuit current is 8.63 A. The battery size is 6,068.63 Ah at 48 V DC based on E_{db}, AD, DOD, η_{BAh} and V_B of 99040 Wh, 1.5, 60 %, 85 % and 48 V. The size of the inverter is 27.58 kVA but the nearest standard size is 30 kVA.



(a) (b) (c)



(d) (e) (f)

Figure 5: Different DG configurations (a) PV-based DG (b) PV/biogas-based DG (c) PV/biogas/natural gas-based DG (d) PV/biogas/diesel-based DG (e) PV/diesel-based DG (f)Diesel-based DG

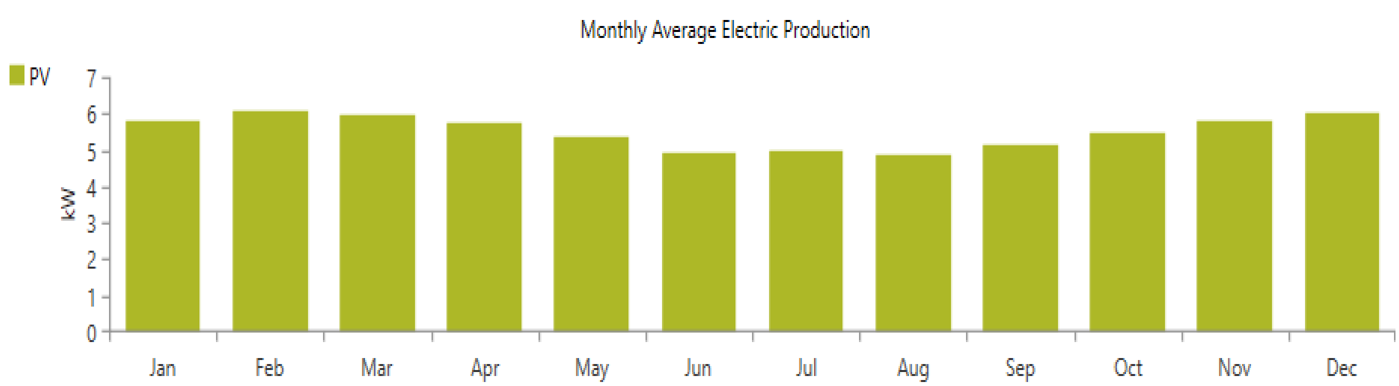


Figure 6: Monthly electric generation from 36.9 kW PV-based DG

3.1.3 PV/biogas/diesel DG system

The PV/biogas/diesel DG system is shown in Figure 5 (d), consisting of 36.9 kW PV, 13.2 kW biogas gen and 13.2 kW diesel gen (D. Gen). The energy produced by the PV, Bio Gen and D.Gen are 48,268, 32,072 and 8,441 kWh/yr which translates to 54.4, 36.1 and 9.51 % contributions, respectively. The UED is 0%. The monthly generation is shown in Figure 9.

3.1.4 PV/diesel DG system

The PV/diesel DG system is shown in Figure 5 (e), which consists of 36.9 kW PV and 13.2 kW diesel generator. The electricity produced by the PV and D. Gen are 48,268 and 18,555 kWh/yr, which translates to 72.2 and 27.8 % contributions. The UED is 0%. The monthly average electric generation is presented in Figure 10.

3.1.5 Diesel-based DG system

The diesel-based DG system is shown in Figure 5 (f), which is rated 13.2 kW. It generates 42,374 kWh/yr of electricity. The UED is 0%. The monthly generation is presented in Figure 11.

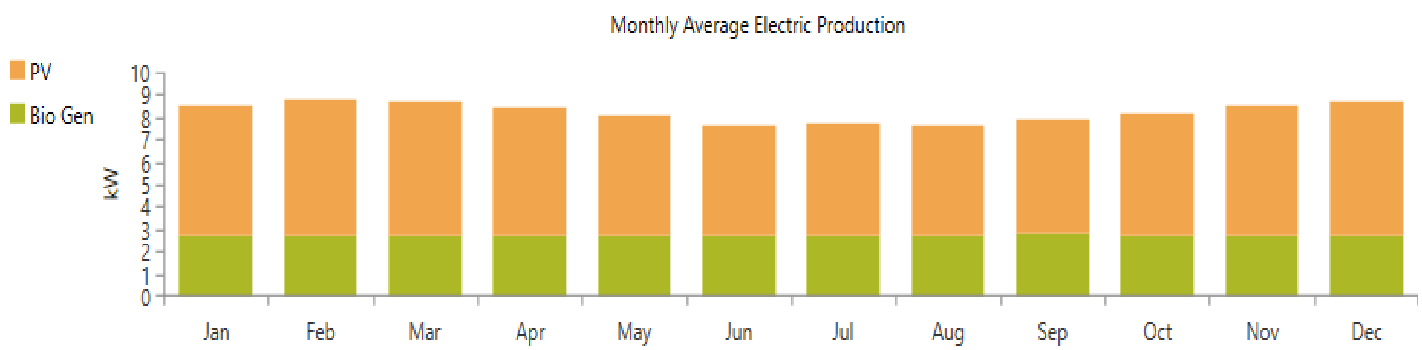


Figure 7: Monthly electric production from the 36.9 kW PV and 13.2 kW biogas generator

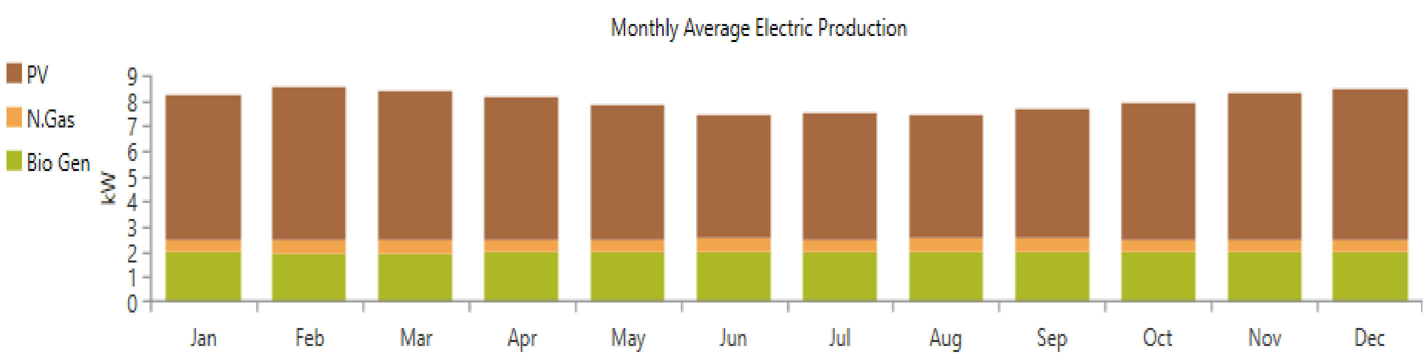


Figure 8: Monthly generation for 36.9 kW PV, 13.2 kW biogas and 13.2 kW natural gas gen

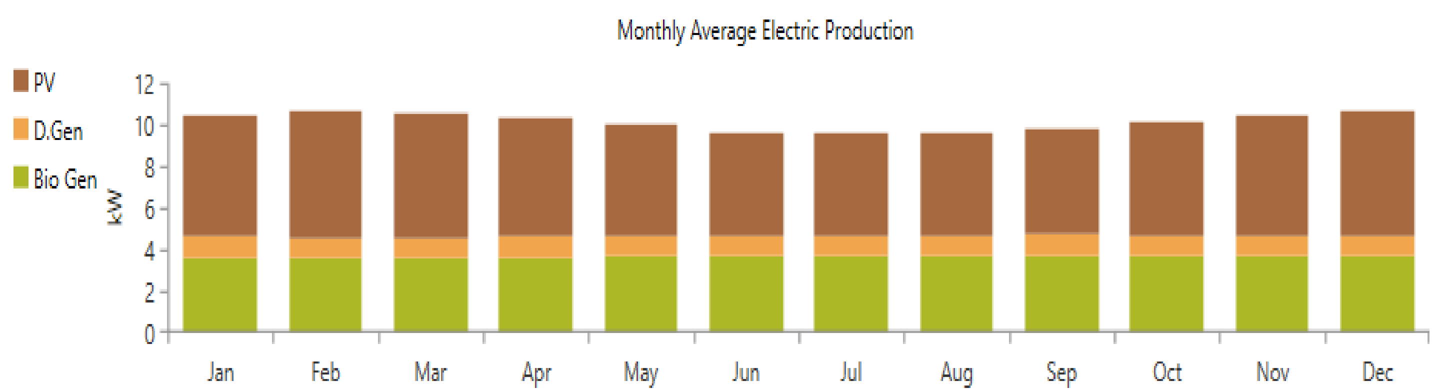


Figure 9: Monthly generation from 36.9 kW PV, 13.2 kW biogas and 13.2 kW D. Gen

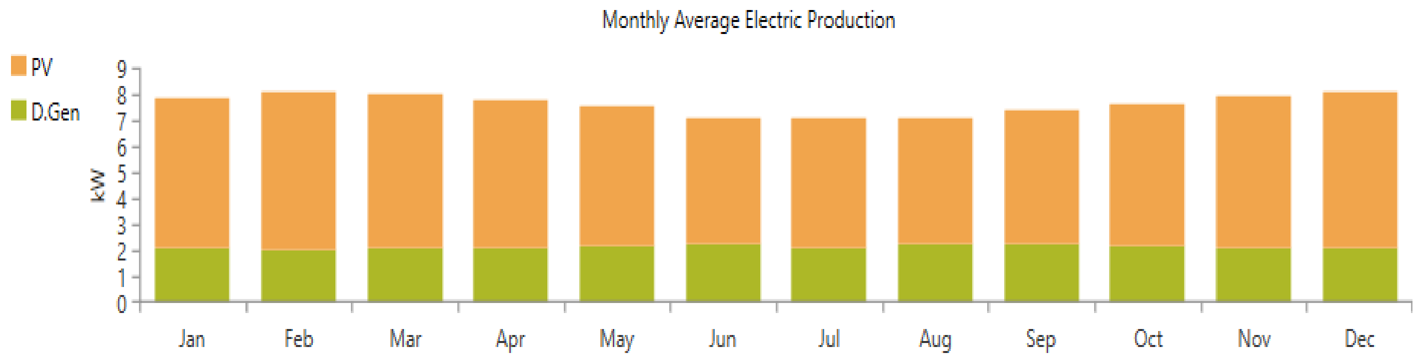


Figure 10: Monthly generation from 36.9 kW PV and 13.2 kW diesel generator

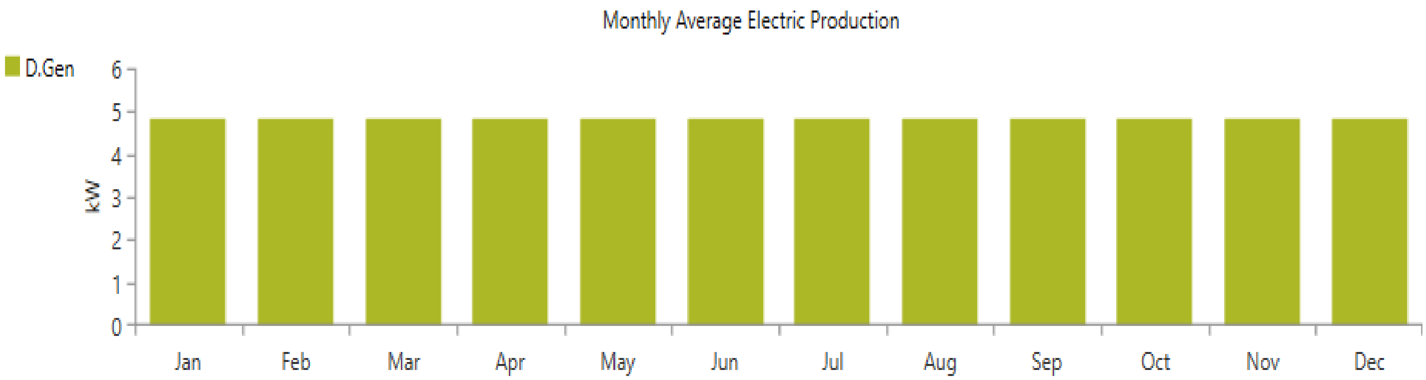


Figure 11: Monthly generation from 13.2 kW diesel-based DG system

The PV-based DG system shown in Figure 5(a), being a renewable energy resource, produced an emission of 0 kg/yr for all the mentioned emissions. This justifies the fact that the PV-based DG system is a clean electricity option, which needs to be promoted.

The introduction of biogas - obtained from burning of sawdust leads to the release of some emission gases, although very minimal, due to the presence of methane. The DG in Figure 5 (b) emits CO_2, CO, UH, PM, SO_2 and NO of 2.21, 0.229, 0.0101, 0.00138, 0 and 0.215 kg/yr, respectively. It is obvious from these results that the emissions from PV/biogas DG are 100% higher than that of the PV-based DG, except for SO_2 that is not also emitted by the system. This DG consumed 14 tons/yr of biomass feedstock.

The addition of natural gas fuel into the DG system as shown Figure 5(c) changes the scenario entirely because of the inclusion of a byproduct of crude oil. This DG emits CO_2, CO, UH, PM, SO_2 and NO of 2,453, 8.30, 0.00659, 0.231, 0 and 17.2 kg/yr. These GHG emissions are higher than the values obtained for the PV/biogas and the PV-based DGs because of the methane and other hydrocarbon contents. This justifies a very high proportion of CO_2, CO, UH, PM, and NO compared to those of the PV/biogas DG. This DG consumed 9.15 tons/yr of biomass feedstock and 1,270 m^3/yr of gas.

The introduction of diesel changes the scenario of PV/biogas of Figure 5 (b), given that diesel is heavier than gasoline. In addition, diesel fuel, being a heavy petroleum fraction, emits relatively high value of CO_2. The PV/biogas/diesel DG system in Figure 5 (d) emits CO_2, CO, UH, PM, SO_2 and NO of 8,952, 56.2, 2.48, 0.337, 21.9 and 52.8 kg/yr, respectively, compared to PV-based, PV/biogas, PV/biogas/natural gas DG options. It is obvious that this DG system has lower CO_2, CO, UH, PM and NO compared to the PV/biogas/natural gas DG system because the natural gas is a cleaner fossil fuel. However, it has a 21.9 kg/yr of sulfur dioxide emission compared to the PV/biogas/natural gas DG system. This DG utilized 21.4 tons/yr of biomass feedstock and 3,418 L/yr of diesel.

The PV/diesel DG in Figure 5 (e) emits CO_2, CO, UH, PM, SO_2 and NO of 15,448, 96.4, 4.25, 0.578, 37.8 and 90.6 kg/yr, respectively. The carbon content in diesel makes the PV/diesel DG emits a high quantity of CO_2 compared to the previous DGs. The values of emissions by the PV/diesel DG system are higher than those obtained for the PV/biogas/diesel DG. This energy system consumed 5,901 L/yr of diesel.

The diesel-based DG system emits CO_2, CO, UH, PM, SO_2 and NO of 40,273, 251, 11.1, 1.51, 98.6 and 236 kg/yr, respectively. The system generates the highest emissions of all the different DGs. This is due to a scenario of 100% utilization of the diesel-based DG system over the year with a diesel consumption of 15,384 L/yr. This justifies why this energy should be utilized in the energy mix as a back-up with reduced percentage contribution. This way, the emissions will be reduced with the utilization of relatively high percentage of renewable energy-based DGs in multi-DG systems. The paper demonstrates that hybrid energy systems perform better than single-source RE systems in terms of reliability and it can also provide clean energy supply [1, 48].

Table 2: *Emissions generated by different DG systems*

Emission	PV-based	PV/biogas	PV/biogas/natural gas	PV/biogas/diesel	PV/diesel	Diesel-based
CO_2 (kg/yr)	0	2.21	2,453	8,952	15,448	40,273
CO (kg/yr)	0	0.229	8.3	56.2	96.4	251
UH (kg/yr)	0	0.0101	0.00659	2.48	4.25	11.1
PM (kg/yr)	0	0.00138	0.231	0.337	0.578	1.51
SO_2 (kg/yr)	0	0	0	21.9	37.8	98.6
NO (kg/yr)	0	0.215	17.2	52.8	90.6	236

4.0 CONCLUSION

This study has presented the design of multi-DG systems for off-grid application based on solar, biomass, natural gas and diesel energy resources. It examined the possibility of powering 20 homes assuming a location in Ogun State, Nigeria as a case study. Also, a techno-environmental analysis planning (TEAP) approach was introduced in the paper with detailed systems simulation and analysis achieved in HOMER environment. The technical design and analysis considered the users' demand requirements, DG systems' component sizes, system configurations, annual electricity delivered, and the system reliability in terms of unmet energy demand (UED). The environmental aspect on the other hand, considered how much emissions are being generated by operating the proposed multi-DG systems compared to a 100% carbon-intensive diesel-based DG system.

The load requirements, solar, ambient temperature and biomass data available solar, biomass data served as crucial input parameters to the HOMER software. The load demand data was based on the authors' field work, while the solar, temperature and the biomass data were based on the literature. The paper modeled, examined and compared different energy configurations such as the PV-based, and the hybrid DGs: PV/biogas, PV/biogas/natural gas, PV/biogas/diesel, PV/diesel, and diesel-based systems. The demand and peak load of the 20 homes are 99.04 kWh/d (i.e., 36,149.6 kWh/yr) and 10.552 kW, respectively. Results revealed that the capacity of the PV-based DG is 36.9 kW, while the size all other generators such biogas gen, natural gas gen and diesel gen is 13.2 kW. The total electricity generated by the mentioned DGs are 48,268, 72,128, 52,646, 88, 781, 66,823 and 42,374 kWh/yr, respectively. The hybrid DGs have a UED value of 0%, compared to 7.84 % obtained for the PV-based DG system. The results further demonstrated that the PV-based DG has zero emissions, while the hybrid DGs produced lower emissions compared to the diesel-based DG that emitted CO_2, CO, UH, PM, SO_2 and NO values of 40,273, 251, 11.1, 1.51,584, 98.6 and 236 kg, respectively.

This study further demonstrates that though non-renewable energy-based DGs are carbon intensive, they are still practically required to be integrated with the RE-based DG systems for reliability purpose. In this case, a higher percentage contribution of RE-based DGs is reasonable to ensure environmental-friendly supply for off-grid locations. The paper can help to plan, design and select reliable and eco-friendly DG systems for remote communities.

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