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Towards Smart Grid Economics Using Distributed Generation Systems-Hybrid Biomass, Solar and Fossil Fuel Plants

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Abstract— Distributed generation (DG) systems have recently gotten a lot of interest, especially in places where electricity supply is inconsistent, such as remote areas. Smart grid DG is yet to be fully implemented with renewable energy power sources (REPS) or fossil fuel generating facilities (diesel/gasoline) depending on resource availability and cost. For small rural villages in Nigeria, this study conducted a complete comparison of these two power-producing systems. The case study location is the Unwana community in Ebonyi state, which is located in Nigeria's South-East geopolitical zone. A total of 100 houses, 8 stores, and 1 public restroom are estimated to be in the neighborhood. The location's average daily consumption is predicted at 240.1 kWh per day, with a peak demand of 41.6kW. To meet the expected load requirement, two distinct systems, a hybrid biomass-solar renewable energy plant and a diesel producing plant, were built, simulated, and optimized. The hybrid plant's determined optimal sizing includes 20kW and 10kW Bio-gas generators, 4.6 kWh PV panels, 31 strings of 12V 1kWh lead-acid batteries, and an 8.65kW converter. Similarly, the best size of the diesel plant consists of 15kW and 30kW diesel generating sets, with the 30 kWh Genset providing 55.1% of total power and the 15 kWh Genset providing the remaining 44.9%. Biomass accounts for 93.7% of the total power generated by the hybrid plant, with solar accounting for the remaining 6.3%. A comparison of the two systems revealed that the diesel plant had an edge only in terms of capital costs. Consequently, the diesel power plant becomes unappealing when additional costs, (particularly fuel expenses) are included. Finally, the results suggest that the diesel producing plant's total Net Present Cost (NPC) over the project's 25-year lifetime will be 105,372,360 Naira, or around 44% higher than the hybrid facility.

Keywords—Renewable Energy, Smart grid Optimization, Economy of Scale, Biomass, Hybrid Plant, Systems modeling

I. INTRODUCTION

Renewable energy methods of power generation have gained much attention lately owing to increasing attention to decarbonization, Climate change focus, and Smart grid evolutions in the 21st century [1], [2]. A Smart grid is an electrical system that incorporates several operational and energy-saving features, such as [3], [4]:

- infrastructure for advanced metering, AMI [5], [6].
- Smart distribution controls and circuit breakers with demand response and home unit control.
- Load control switches and smart appliances [7].
- renewable energy resources, such as the ability to charged electric car batteries or larger arrays of batteries recycled from these, or other types of renewable energy resources (RERs).

In power-challenged environments, electrical generation and storage are implemented with a small range of grid-connected or distribution system-connected devices referred to as distributed energy resources in distributed generation. This is commonly known as distributed energy, on-site/on-demand generation, or decentralized energy (DER). In context, renewables have gained massive attraction in SG/DER as a result of the desirable attributes and advantages it possesses over conventional fossil fuel generation methods, (i.e., cleanliness and affordability) [8].

Since the availability of these resources used for different methods of power generation varies from place to place, the choice of approach regarding electricity generation largely depends on location specifics. Using renewable energy sources to generate electricity has significant advantages over using fossil fuels in the SG ecosystem [9].

The most challenging issue that comes with fossil fuel utilization in some locations is its unavailability and high cost. Fossil fuel is not readily available in many locations around the world, hence described to be distinctly and unfairly distributed [10]. RERs on the other hand can be said to be almost geographically balanced in the sense that every location in the world experiences some amount of sunshine and wind [11]. Wood and other biomass materials are derivable in different quantities depending on the environment. Sufficient water for hydro projects can be derived in some places while geothermal energy is another

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existing source of energy that is recently being harnessed [12].

The major driving forces fostering the use of RERs for power generation include reduced emission of greenhouse gases which reduces global warming and improves general public health [10-13]. Other merits include inexhaustibility, economic benefits like the creation of jobs, and reliability in the sense that distributed generation systems are less prone to massive failure.

However, the preferred method of electricity generation is location-dependent within the smart grid domain [14-15]. When considering the method to be used for electricity generation in different locations, availability and cost of resources are the utmost factors that are meant to be considered. In some locations, fossil fuels can be obtained in abundance and at a relatively cheaper rate than other locations thus giving rise to the need for economic comparison with the available RERs in the location of interest.

The distribution system must become more adaptable to meet impending difficulties and successfully integrate renewable energies and active demand response. The term "smart grid" has gained popularity in recent years, referring to a wide range of technologies targeted at upgrading the distribution system [16] as part of energy policies based on long-term viability and efficiency. A lot of work is being done right now to figure out the prospective costs and advantages of implementing a feasible economic integration of renewables [16]. However, because of a lack of practical knowledge, the real implementation of the SG models appears complex from an economic perspective. Owing to cost-effectiveness, SG systems running on distributed energy resources have the following benefits – reliability, network design flexibility, efficiency, load adjustment/load balancing, peak curtailment/leveling, and time-of-use pricing. It provides for Sustainability, market enablement, demand response assistance, and a platform for advanced services are among the other advantages. Furthermore, Megabits are provided, and kilobits are used to control electricity.

A. *Summary of contribution*

i. To compare the economic feasibility of using a hybrid solar-biomass renewable energy system concerning using diesel generators to power Unwana community in Ebonyi state located in the south-east geopolitical zone of Nigeria.
ii. To simulate and optimize two generating plant systems with the HOMER Pro version.
iii. To derive computational metrics for the economy of scale in smart grid ecosystems.

The rest of this paper is structured as follows. Section II describes related works on renewable energy systems. Section III presents grid contexts on DERs, solar, bio-mass, load assessment. Section IV focuses on computational integration. Section V presents the diseal plant. Section VI describes the results while concluding in Section VII.

II. RELATED WORKS

A. *Review Concept*

To put the study in context, this section reviews relevant works on optimization design in relation to hybrid renewable energy systems (solar [17], [18], [19], [20] and biomass energy resources, [21], [22], [23], etc.).

The authors [24] examined how to optimize the design of a hybrid renewable energy system that uses solar and biomass energy resources. The goal is to achieve optimal system performance by proper HRES sizing, sensitivity analysis, and component selection. The authors [25] presented a techno-economic feasibility analysis for meeting the energy needs of Moroccan rural villages. To complete the optimization study for the wood chips and PV modules, the work investigated several hybrid systems such as wood chips and PV modules to complete the optimization analysis for the rural community. The authors [26] investigated a modeling methodology for minimizing the configuration costs of a hybrid system including solar panels, wind turbines, and biomass fuel. Appendix I summarizes a systematic evaluation of the literature on hybrid renewable energy systems.

From various works in literature, it is clear that the utilization of HES sources is majorly significant for power generation at remote rural localities [19], [20]. A hybrid renewable energy system (HRES) [21-28] is a careful integration of more than two renewable power production systems via intelligent automation, as well as adding energy storage for improved performance. To derive HRES reliability in this scenario, the design decision must include a proper renewable energy (RE) system, design unit size, and storage system [29-45] provide a full overview of several HRES-based technologies (e.g., fuel cell (FC), wind, solar photovoltaic (PV) /concentrated solar thermal power (CSP), biomass, geothermal, etc.).

Consequently, this study, focused on the Smart grid Techno-economic analysis while carrying out a comprehensive comparison of two methods of power generation for small rural settlements in Nigeria.

III. MATERIALS AND METHODS

A. *Scenario Description*

Considering the SG domain, a full comparison of the two recognized power production strategies for rural settlements in Nigeria was investigated. A case study was constructed at the Unwana community in Ebonyi state, which is located in Nigeria's South-East geopolitical zone. A total of 100 dwellings, 8 stores, 1 public primary/secondary school, 1 community hall, 1 community health facility, community water project, street lighting, and miscellaneous load are projected to be present in the region. Data collation of the load profile and the available renewable energy resources of the study location were carried out. Afterward, the design, simulation, and optimization of two different generating systems (the hybrid biomass-solar renewable energy plant and the diesel generating plant) were explored. This was done to the available resources and the estimated electric load that is to be satisfied. Also, economic comparison of the two methods designed to power the study location was carried out. The simulation and optimization of the two generating systems were done in HOMER Pro version 3.11 environments [29] running on a localized server machine (HP intel-core-i5).

B. Data on Renewable Energy Resources

This section displays statistics on renewable energy resources collected for the research site (Unwana community). The study location's coordinates and climate type are shown in Table 1.

TABLE 1. LOCATION COORDINATES AND CLIMATE TYPE OF THE UNWANA COMMUNITY

Study location	Geo-political zone	Coordinates	Climate type
Unwana (Ebonyi state)	South-East	5.524^{o}N/7.567^{o}E	Tropical Savannah.

C. Distributed Energy Resources (Solar Context)

Table 2 displays the average monthly irradiance, clearance index, and temperature for the Unwana community, as acquired from NASA's database using the coordinates. Table 2 summarizes the daily radiation charts, clearance index, and temperature of the tested location in Figure 1

TABLE 2. AVERAGE MONTHLY IRRADIANCE, CLEARANCE INDEX, AND TEMPERATURE OF THE STUDY LOCATION

Month	Daily radiation ($kWh/m^2/day$)	Clearness index	Temperature (^oC)
January	5.530	0.588	25.350
February	5.590	0.562	25.760
March	5.532	0.512	25.680
April	5.090	0.488	25.770
May	4.720	0.466	25.650
June	4.310	0.435	24.770
July	3.850	0.386	24.050
August	3.770	0.368	23.940
September	3.940	0.381	24.150
October	4.270	0.426	24.450
November	4.840	0.510	24.680
December	5.290	0.576	24.710
Average	4.71	0.476	24.91

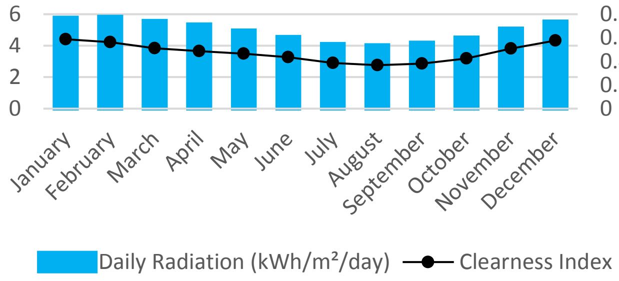


Fig. 1a. Daily radiation charts, clearance index, and temperature of Testbed location *A*.

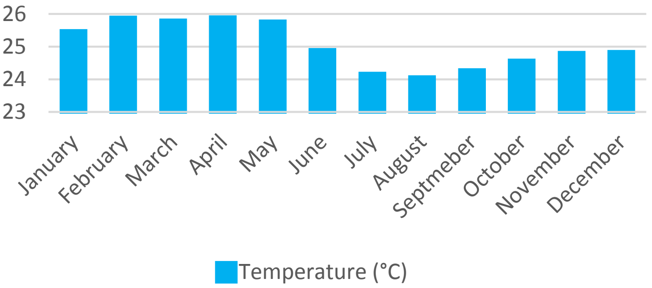


Fig. 1b. Daily radiation charts, clearance index, and temperature of Testbed location *B*.

D. Distributed Energy Resources (Biomass Context)

Rice husk and rice straw, which are rice processing by-products, are the primary biomass feedstock materials available in the area. Ebonyi state produces roughly 19000 metric tons of rice paddy per year [52], making it Nigeria's fifth largest rice producer. According to [53], an average of 1.5 metric tons of rice husk can be delivered daily from the nearest rice mills to any site in Unwana for #20,000 naira (labor and transportation), which is around $56 at the current 360 naira to one US dollar exchange rate. This equates to a fuel cost of almost $37 per ton [53]. Table 3 shows the results of a proximal analysis in Malaysia [54].

E. Assessment of Load Demand

As stated in Table 4, the load is divided into two groups in this study: residential and social infrastructural loads. It presents a summary of the location's daily load demand for a day during the rainy season (March to October) and a day during the dry season (November to February) (November to February). The domestic load will be classified category A and the social infrastructure load will be branded category *B* for simplicity. The load profile in this section is an assumption based on the community's customer classification and cluster method.

TABLE 3. CONTENTS AND CALORIFIC VALUE OF DRIED RICE HUSK

Fixed carbon (% dry basis)	Volatile matter (% dry basis)	Ash (% dry basis)	Moisture (% wet basis)	LHV MJ/kg (% dry basis)	Bulk density kg/m^3
13.49	62.95	18.15	10.40	14.80	91.46

TABLE 4. SUMMARY OF THE ESTIMATED LOAD PROFILE FOR THE STUDY LOCATION [53].

Load description	Number in use	Power rating (watts)	Power rating (kW)	Total rating (kW)	Rainy season (March-October)		Dry season (November-February)	
					Hours/day	**kWh/day**	**Hours/day**	**kWh/day**
Category A: Domestic load								
Lighting(CFL)	4	18	0.018	0.072	7	0.504	7	0.504
Television	1	80	0.08	0.08	5	0.4	5	0.4
DVD player	1	20	0.02	0.02	2	0.04	2	0.04
Radio	1	10	0.01	0.01	8	0.08	8	0.08
Ceiling fan	2	30	0.03	0.06	20	1.2	10	0.6
Total for 100 households				**24.2**		**222.4**		**162.4**
Category B: Social infrastructure load								
1. Primary health center								
Lighting (CFL)	6	18	0.018	0.108	12	1.296	12	1.296
Refrigerator	1	480	0.48	0.48	14	6.72	12	5.76
Television	1	80	0.08	0.08	6	0.48	6	0.48
Ceiling fan	3	30	0.03	0.09	21	1.89	13	1.17
Total				**0.758**		**10.386**		**9.379**
2. Public primary/ secondary school								
Lighting (CFL)	8	18	0.018	0.144	0	0	0	0
Ceiling fan	3	30	0.03	0.09	5	0.45	2	0.18
Total				**0.234**		**0.45**		**0.18**
3. Community hall								
Lighting (CFL)	6	18	0.018	0.108	0	0	0	0
Television	1	80	0.08	0.08	8	0.64	8	0.64
Ceiling fan	4	30	0.03	0.12	9	1.08	6	0.72
Total				**0.308**		**1.72**		**1.36**
4. Market/shops								
Lighting (CFL)	8	18	0.018	0.144	3	0.432	3	0.432
Refrigerator	2	480	0.48	0.96	15	14.4	12	11.52
Ceiling fan	4	30	0.03	0.12	15	1.8	10	1.2
Total				**1.224**		**16.632**		**13.152**
5. Street lights								
LED light panel	40	30	0.03	1.2	11	13.2	11	13.2
Total				**1.2**		**13.2**		**13.2**
6. Community water project								
Water pumping machine (deferrable load)	2	1134	1.134	2.268	3	6.804	3	6.804
Total				**2.268**		**6.804**		**6.804**
Total consumption				**30.192**		**271.592**		**206.475**

IV. COMPUTATIONAL INTEGRATION (HYBRID SOLAR BIOMASS POWER PLANT

The Hybrid Optimization Model for Renewable Energy (Homer) Pro version 3.11.2 [26] was chosen to conduct a contextual techno-economic feasibility analysis using biomass potential and sun irradiance data from Ebonyi State in this study. HOMER analysis was used to obtain the appropriate scenarios as a case setting. Essentially, the research yielded the total NPC, the cost of electricity (COE), and biomass use. In this case, the design was on selecting optimal power generation and storage components that would take advantage of available solar and biomass resources to fulfill load demand. PV solar panels, storage batteries, a power converter, and a controller are among the components employed.

A. Solar Plant

A typical flat-plate PV was used for this design. To optimize for the required capacity of PV panels to be employed, HOMER Pro was used. The Solar PV parameters are listed in Table 5.

TABLE 5: DETAILS OF THE SOLAR PV

Parameters	Value	Parameters	Value
Capital cost	$3000/ kW	Efficiency	13%
Replacement cost	$3000/kW	Operating temperature	47^0C
Operation/maintenance cost	$10/year	Temperature coefficient	-0.5
Lifetime	25 years	De-rating factor	80%

HOMER platform explored Equ.1 to calculate the output of the PV array for each time step:

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) \left[1 + \alpha_P (T_C - T_{C,STC})\right] \quad (1)$$

Where Y_{PV} is the rated capacity of the PV array(kW), f_{PV} The PV de-rating factor(%), $\bar{G}_T$ is the solar radiation incident on the PV array(kW/m^2), $\bar{G}_{T,STC}$ is the incident radiation at standard test conditions(1kW/m^2), α_P is The temperature coefficient of power(%/°C), T_C is the PV cell temperature(°C) and $T_{C,STC}$ is the PV cell temperature under standard test conditions(25°C).

B. Biomass Generator

Two generic biogas generators are considered adequate for the system in the smart grid design. To optimize with HOMER Pro for the needed sizing while taking into account the most cost-effective running sequence, inputs ranging from 0 to 50kW are given in the search space. Table 6 lists the biogas producers that were chosen.

TABLE 6: BIOGAS GENERATORS SPECIFICATIONS.

Parameters	Value	Parameters	Value
Capital cost	$500/kW	Operation/ maintenance cost	$0.03/operating hour
Replacement cost	$500/kW	Lifetime	20,000 hrs.

Fuel consumption of the biogas generator is determined by the fuel curve equation as follows:

$$F = F_0 Y_{gen} + F_1 P_{gen} \quad (2)$$

Where F is the fuel consumption, F_0 is the fuel curve intercept coefficient (kg/hr/kW $_{\text{rated}}$) defined as the no-load fuel consumption of the generator divided by its rated capacity, F_1 is the fuel curve slope (kg/hr/kW $_{\text{output}}$) defined as the marginal fuel consumption of the generator, Y_{gen} is the rated capacity of the generator (kW), P_{gen} is the electrical output of the generator (kW).

C. Battery Systems

In the Smart grid model, a generic 12V, 1kWh lead-acid battery was used in the design for energy generation. The details of the selected storage battery are given in Table 7.

TABLE 7: BATTERY SPECIFICATIONS

Parameters	Value	Parameters	Value
Capital cost	$300/kW	Nominal capacity	1kWh
Replacement cost	$300/kW	Maximum capacity	83.4Ah
Operation/maintenance cost	$10/year	Roundtrip efficiency	80%
Lifetime	10years	Maximum charging current	16.7A
Nominal voltage	12V	Maximum discharge current	24.3A

The battery autonomy is calculated as follows:

$$A_{batt} = \frac{N_{batt} V_{nom} Q_{nom} \left[\frac{1-q_{min}}{100}\right] (24h/d)}{L_{prim,ave} (1000Wh/kWh)} \quad (3)$$

Where A_{batt} is the storage bank autonomy (hr.), N_{batt} is the number of batteries in the storage bank, V_{nom} is the nominal voltage of single storage (V), Q_{nom} is the nominal capacity of single storage (Ah), q_{min} is the minimum state of charge of the storage bank (%) and $L_{prim,ave}$ is the average primary load (kWh/d).

D. Converter Systems

Table 8 highlights the design parameters of the converter deployed in the smart grid ecosystem.

TABLE 8: DETAILS OF THE CONVERTER

Parameters	Value	Parameters	Value
Capital cost	$300/kW	Lifetime	15years
Replacement cost	$300/kW	Inverter efficiency	95%
Operation/maintenance cost	$0	Rectifier efficiency	90%

E. System Economics and Constraints

For the grid design, the economic inputs include the annual inflation rate and annual interest rate which was gotten from the Central Bank of Nigeria. The economics and constraint inputs are given in Table 9.

TABLE 9: ECONOMIC AND CONSTRAINT INPUTS

Economics	Value	Constraints	Value
Nominal discount rate	14%	Maximum annual capacity shortage	0%
Expected inflation rate	12.5%	Minimum renewable fraction	50%
Project lifetime	25 years	Operating reserve	10% of load

The resulting schematic of the hybrid plant after adding all the required components is shown in Figure 2.

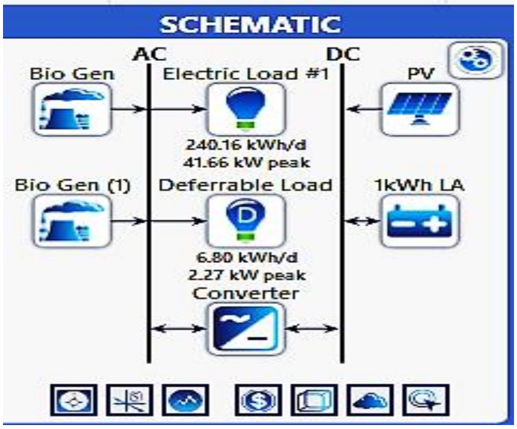


Fig. 2. Schematic of the hybrid biomass-solar plant

V. DIESEL GENERATION PLANT

In the Smart grid context, a conventional generating plant that uses diesel as fuel was designed to satisfy the same load profile of the study location. The system was optimized for the lowest possible cost by running simulations on HOMER Pro with different combinations of different sizes of diesel generating sets. In the search space for the generator size, a combination of 10kW to 50kW giving intervals of 5kW was tested. The schematic of the configuration can be seen in Fig. 3. The price of diesel was set to $0.6 which is the dollar equivalent of the price of diesel in Nigeria which is 200 Naira per liter.

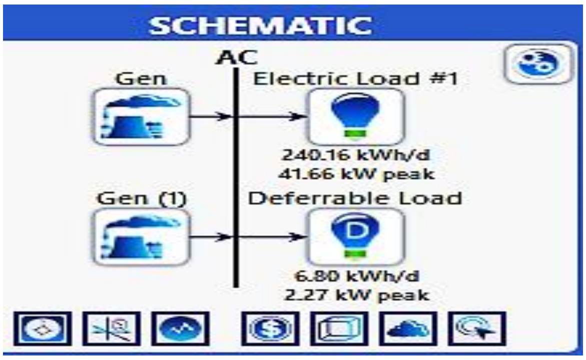
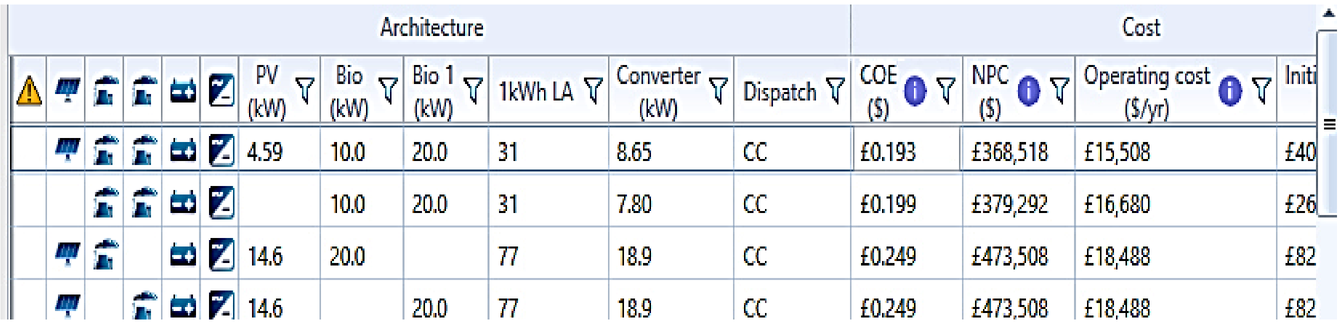


Fig. 3. Diesel generating system schematic.

VI. RESULTS AND DISCUSSIONS

A. Hybrid Biomass-Solar Plant

The optimization results from the simulation computations are shown in Figure 4. In this context, the system's various possible configurations are listed and sorted by their NPC from lowest to highest. The plant with the lowest NPC is deemed to be the most viable. Table 10 shows the architecture of the system with the lowest NPC cost.



PV (kW)	Bio (kW)	Bio 1 (kW)	1kWh LA	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initi
4.59	10.0	20.0	31	8.65	CC	£0.193	£368,518	£15,508	£40
	10.0	20.0	31	7.80	CC	£0.199	£379,292	£16,680	£26
14.6	20.0		77	18.9	CC	£0.249	£473,508	£18,488	£82
14.6		20.0	77	18.9	CC	£0.249	£473,508	£18,488	£82

Fig. 4. Hybrid biomass-solar plant optimization result

TABLE 10. SYSTEM COMPONENTS AND CAPACITIES

Component	Capacity	Component	Capacity
Biogas Generating set 1	20 kW	12V 1kWh lead-acid battery	31 strings in parallel
Biogas Generating set 2	10 kW	System converter	8.65 kW
Flat plate PV	4.59 kW		

B. Hybrid Biomass-Solar Plant System Summary

The proportions of power generated by the generating components are shown in Figure 5. The data from the chart is summarized in Table 11. According to the table, the biogas Genset 2, which is a 20kW generator, provides the most electricity, accounting for 49.9% of the total output.

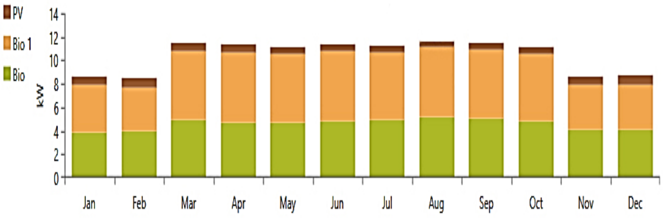


Fig. 5: chart of generating proportions of the bio generators and PV system

TABLE 11. ENERGY PROFILE SUMMARY FOR THE HYBRID PLANT.

Component	Production (kWh/year)	%
Flat plate PV	5,771	6.30
Biogas genset (10kW)	40,151	43.8
Biogas genset (20kW)	45,740	49.9
Total	91,663	100

C. *Hybrid-Biomass-Solar Plant Cost Economy*

Table 12 summarizes the expenses of each system component as well as the total net present cost. The PV plate has the largest initial cost but the lowest operating cost, whereas the biogas generators have a high operating cost due to fuel costs. The Naira equivalent of the total NPC is 132,666,343. (one hundred and thirty-two million, six hundred and sixty-six thousand, three hundred and forty-three Naira).

TABEL 12: HYBRID SYSTEM COST SUMMARY

Components	Capitals($)	Replacement($)	O&M($)	Fuel)$)	Salvage($)	Total ($)
Generic 1KWh Lead Acid	9,300.00	15,281.98	6,553.91	0.00	2,229.22	27,796.68
Generic Bigas Genset	5,000.00	24,890.56	30,780.13	92,515.81	-3,352.68	149,833.82
Generic Bigas Genset (1)	10,000	24,885.98	35,391.12	105,451.35	-3,680.32	172,048.13
Generic flat-plate PV	13,766.91	0.00	970.18	0.00	0.00	14,101.90
System Converter	2,595.41	2,127.75	0.00	0.00	-621.27	4.101.90
System	40,662.33	67,166.27	73,695.35	197,967.16	-10,993.49	368,517.62

D. *Diesel Generating Plant Results*

The system architecture with the lowest NPC for the diesel generating plant from the simulation consists of one 15kW generator and one 30kW generator as shown in Table 13.

TABLE 13: SYSTEM OUTCOME FOR DIESEL PLANT

Component	Capacity
Diesel Generating Set 1	15kW
Diesel Generating Set 2	30kW

Fig. 5 shows the proportions of power generated by the diesel generating sets while Table 13 shows the electricity production and consumption values extracted from the result.

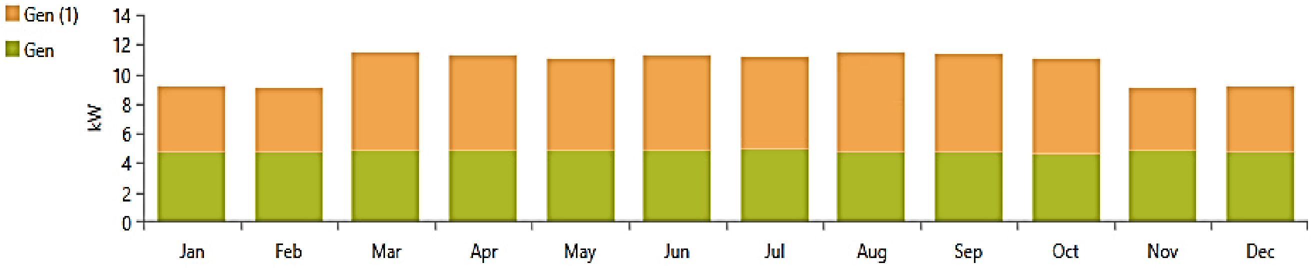


Fig. 5. Chart of generating proportions of the diesel generating sets

TABLE 14. ENERGY PRODUCTION AND CONSUMPTION SUMMARY OF THE DIESEL PLANT

Production	kWh/yr	%		Consumption	kWh/yr	%
30kW Diesel Gen	51,022	55.1		AC Primary load	87,644	97.25
15kW Diesel Gen	41,577	44.9		Deferrable load	2,483	2.75
Total	92,600	100		Total	90,126	100

E. *Diesel Generating Plant Cost Summary*

In this study, Table 15 shows the cost summary of the diesel power plant. As depicted, it is obvious that the fuel column has the highest cost. The total NPC amounts to a naira equivalent of #238,036,543 (i.e., Two hundred and thirty-eight million, thirty-six thousand, five hundred and forty-three) Naira.

F. *Economic Comparison between the Hybrid Plant and the Diesel Plant*

Table 16 shows a cost comparison of both the hybrid power plant and the diesel power plant while figure 6 is a chart depicting the cost comparison of the two plants.

TABLE 15: COST SUMMARY OF THE DIESEL GENERATING PLANT

Components	Capitals($)	Replacement($)	O&M($)	Fuel)$)	Salvage($)	Total ($)
Generic Diesel Genset	7,5000.00	62,822.72	57,225.16	181,751.37	-5,251.19	304,048.05
Generic Diesel Genset (1)	15,000.00	63,066.95	64,160.68	219,036.17	-4,093.23	357,170.57
System	22,500.00	125,889.67	121,385.84	400,787.53	-9.344,42	661,218.62

TABLE 16: COST COMPARISON BETWEEN HYBRID BIOMASS-SOLAR POWER PLANT AND THE DIESEL POWER PLANT (VALUES ARE IN NAIRA)

Plant	Capital	Replacement	O&M	Fuel	Salvage	Total (NPC)
Hybrid plant	14,638,403	24,187,057	26,530,326	71,268,178	3,957,656	132,666,343
Diesel plant	8,100,000	45,320,281	43,698,902	144,283,511	3,363,991	238,038,703
Difference	6,538,403	-21,133,224	-17,168,576	-73,015,333	593,665	-105,372,360

From Table 16 and Figure 6, it can be deduced that in terms of cost, the only advantage the diesel generating plant has over the hybrid biomass-solar power plant is the lower capital cost. The diesel generating plant is unattractive when it comes to the other costs, especially the fuel cost. The total NPC of the diesel generating plant over the 25 years lifetime will cost an extra 105,372,360 Naira which is approximately 44% more than that of the hybrid plant. The system is considered to have a lifetime of 25 years. This provides insights from a deployment perspective for the various stakeholders interested in hybrid biomass-solar project investments in Nigeria. Overall, this study concludes that such a plant offers a more feasible option to use in the case study location including other locations having similar conditions.

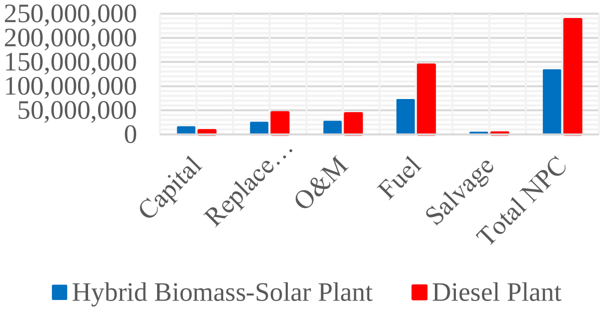


Fig. 6. Chart showing Cost comparison of the hybrid biomass-solar power plant and the diesel power plant

VII. CONCLUSION

This paper has compared the two methods of electricity generation namely hybrid solar-biomass renewable energy system and conventional diesel generating plant within SG infrastructure. Unwana community located in the southeast geopolitical zone was adopted as the study location due to the availability of renewable energy resources (biomass and solar). Both methods of generation were able to satisfy the daily load demand of the study location which is an average of 241kWh/day with a 41kW peak load with no shortage in capacity. The diesel power plant is found to have an advantage only in terms of capital cost with an initial capital of 8,100,000 Naira which is approximately 44.7% less than that of the hybrid solar-biomass plant which is 14,638,403 Naira. The diesel plant becomes undesirable in the long run when considering all other costs especially fuel costs. The total NPC for the 25 years project lifespan of the diesel power plant is 238,038,703 Naira which is approximately 44.3% higher than that of the hybrid plant (132,666,343). Therefore, it can be concluded that the renewable hybrid power plant is a better option for power generation for this study location and other locations with the similar climatic condition

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APPENDIX I. HRES AND TECHNIQUES FOR POWER CHALLENGED ENVIRONMENTS

Output Type	References	Approach	Rural location	Results
AC	[27]	Techno-economic analysis and optimization of HRES viz: solar panels, batteries a geothermal generator & a biomass generator	Oradea, Romania	Achieved the optimization of RES with PV*Sol software
AC	[28]	Techno-economic analysis of off-grid solutions for two remote areas for Wind system with storage and a Solar-Biomass system	Mbandana & Dikgomo South Africa	Determination of ideal HRES systems viz Solar - Wind system with storage and a Solar-Biomass system with storage for optimal off-grid systems.
AC	[29]	Techno-economic analysis for designing a stand-alone hybrid PV/wind/diesel/battery system while minimizing the Cost of Energy (COE) and the CO_2 emission	Perumal Kovilpathy, Tamil Nadu, India	-Determination of the capital cost, cost of energy, NPC for different energy resources based on the load demand. - Optimized configuration of a hybrid system. - Determination of PV - diesel - battery HES as most economical HES.
AC	[29]	Cost-effective modeling of HES for remote rural areas.	Kharagpur, India	Design of a six-stage methodological framework for the small-scale HES

AC	[30]	Techno-economic analysis via life cycle cost comparison of Mix-hybrid systems & individual stand-alone systems.	MANIT, Bhopal, India	Determination of life cycle cost analysis of Mix-HES & individual stand-alone systems.
AC	[31]	Techno-economic analysis on a HES solar, biomass, and human waste is developed	Nepal, India	Integration of the HES in energy security of Kathmandu University.
AC	[32], [33]	Optimum decentralized solar PV-wind-biomass-fossil fuel-based hybrid power system	Bangladesh	Simulated four cost-effective different fuel combinations, & Co-firing with biomass to reduce pollution to about 50%.