Optimum hybrid configuration for off-grid rural electricity generation in the six geopolitical zones of Nigeria.

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Optimum Hybrid Configuration for Off-grid Rural Electricity Generation in the Six Geopolitical Zones of Nigeria

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Introduction

Electricity access constitutes an indispensable requirement for meaningful socio-economic growth in any nation. However, about 1.26 billion people globally (18% of global population) are without electricity access, majority of which dwell in the two developing continents of Asia and Africa where rural population is profoundly affected (WDI, 2016). In Nigeria, Africa's leading and most populous economy, over 90 million people, about 55% of the population is without access to power supply (EIA, 2015). In addition, only 30% of the rural communities is connected to the grid thus leaving larger proportion of the population without electricity access.

Given the above background, this study aims at developing optimal hybrid system harnessing the available renewable energy resources (small-scale hydropower (SHP), solar Photovoltaic (PV) and wind) for power generation, especially in remote/rural areas without access to the main grid line, thereby improving electricity access in a sustainable manner. The paper is organised thus: section one provides succinct introduction, section two gives an overview of the Nigeria's power access situation alongside review of relevant literature. The third section expounds the methodology employed for the techno-economic analysis. section four offers the results and findings of the study whereas, the conclusion is given in section five.

Methodology:

For this study, six of sites, one from each geopolitical zone, with potential for SHP identified in the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) Baseline Report (2012) are considered (see details Table 1 below).
A hypothetical remote community of 50 households, comprising of about 400 to 500 people in total is designed for each study location. A community clinic, school, hall, 5 commercial shops, 5 street lights, 2 agro-processing centres together with 3 water pumps and 2 irrigation pumps is also included. For the modelling, simulation and techno-economic analysis of all necessary inputs, Hybrid Optimization Model for Electric Renewable (HOMER) software is utilized. Four system configurations namely SHP, PV, wind, diesel generator (DG) and battery systems are considered. Additionally, a sensitivity analysis is performed for key sensitive variables of the hybrid system.
Data are sourced from United States National Aeronautics and Space Administration (NASA) database, Nigerian Meteorological Agency, River Basin Development Authority (RBDA) of Nigeria etc.

Results

Firstly, the study identifies a list of feasible hybrid system setups for electricity generation in remote locations across the six geopolitical zones of Nigeria. Secondly, the finding unravels the most economically viable option based on total net present cost (NPC), per unit cost of electricity (COE) and Renewable Fraction (RF) for all the considered zones. Thirdly, the result unleashes the significant disparity in the CO_2 emissions level of the proposed hybrid system as compared to the stand-alone DG system. Lastly, the result reveal the environmental benefit, in terms of annual GHGs cum particulate (CO_2, SO_2 and NOx) emission savings from the proposed hybrid system in all the locations.

Conclusion

Results from this research show that hybrid generation mix at off-grid locations has the potential of supplying cost-effective and environmentally friendly electricity to remote/rural communities across the six geopolitical zones of Nigeria. The study thus provides invaluable insight into developing appropriate electrification plan, implementation strategies alongside supportive mechanisms by the concerned stakeholders to curtail the lingering electricity crisis in Nigeria.

Keywords: Cost of Electricity (COE), Diesel Generator (DG), Hybrid Optimization Model for Electric Renewable (HOMER), Net Present Cost (NPC), Optimal Hybrid Mix, Renewable Fraction (RF)

Reference

Energy Information Administration (EIA), (2015): Country Analysis Brief – Nigeria, Februarary 2015, 1-10

ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE), (2012): Baseline Report on existing and potential small-scale hydropower in the ECOWAS region, Prala Cape Verde, 1-106.

World Bank Development Indicator (WDI), 2016 at www.worldbank.org/ (last visited on 13th May, 2017)

Table 1: Selected Location in each of the six Geopolitical Zones of Nigeria

Geo-Political Zone	State	Site Location	Geographic Coordinate	
			Latitude (N)	Longitude (E)
North East (NE)	Gombe	Balanga	9°55'20"	11°35'58"
North West (NW)	Kastina	Kabomo	11°32'33"	7°28'43"
North Central (NC)	Kwara	Asa Dam	8°24'50"	4°26'28"
South East (SE)	Ebonyi	Edukwu	6°43'15"	8°10'31"
South West (SW)	Ekiti	Elemi	7°54'19"	5°16'20"
South South (SS)	Delta	Ibrede	5°32'60"	6°23'60"

Source: the Study

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Aim

- To develop optimum hybrid configuration suitable for rural power generation in each geopolitical zones of Nigeria.

Background

- Electricity is essential for basic activities. In rural areas, electricity access fosters productivity as well as socio-economic transformation
- Nevertheless, about 1.26 billion people worldwide (18% of global population) are without electricity access
- In Nigeria, 55% of the population is without electricity access. In addition, only 30% of the rural communities are electrified, thus leaving 70% of the rural population without electricity access
- To address this situation, this study attempts to develop a hybrid configuration for rural electricity generation in each of Nigeria's six geopolitical zones.

Selected Locations and Energy Resources Assessment

The study selects six villages/remote locations with SHP potentials (one from each of the Nigerian six geopolitical zones) as presented in Table1:

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Energy Potential Assessment at Six Selected locations in Nigeria

Figure 1: Calibrated hydro Flow Profile

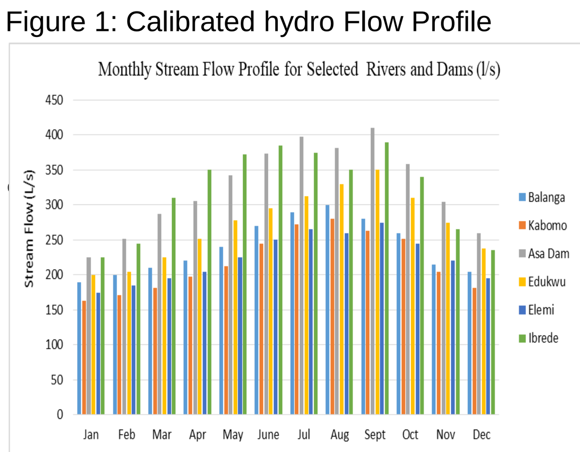


Figure 2: Solar Radiation Profile

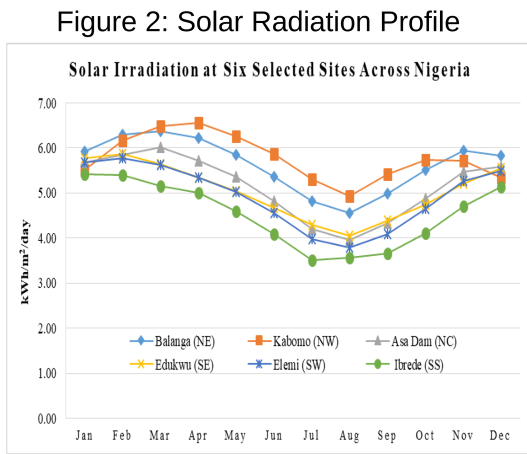
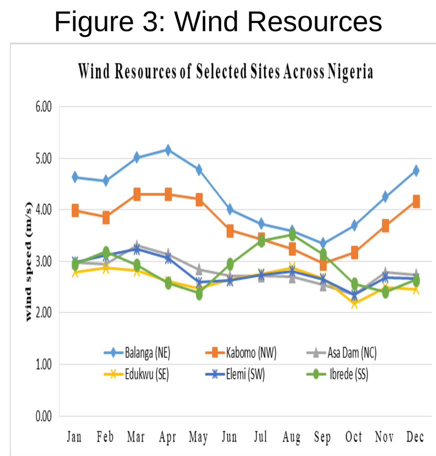


Figure 3: Wind Resources



Methodology - System modelling

- The study uses Hybrid Optimization Model for Electric Renewable (HOMER) modeling tool; developed by NREL (National Renewable Energy Laboratory, USA)
- Combination of small hydropower (SHP), wind turbines, solar PV (SPV) systems, batteries, and diesel generator (DG) for backup are considered (see Figure 4).

Figure 4: Schematic system configuration

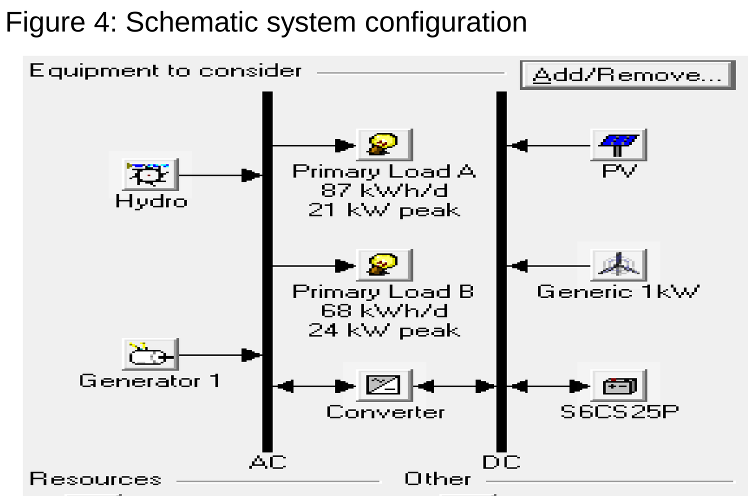
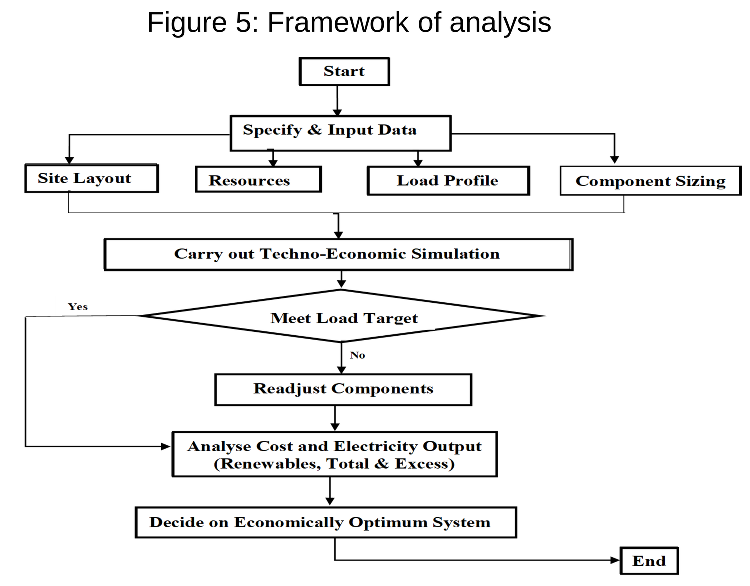


Figure 5: Framework of analysis



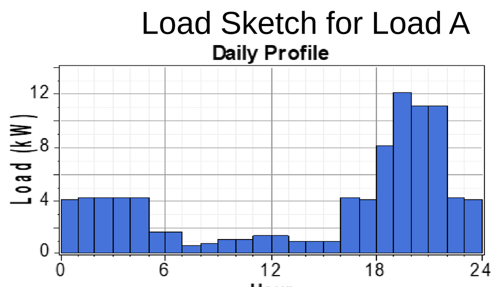
Village Load Profile

- A hypothetical remote/rural community of 50 households comprising of about 400 to 500 people. A community clinic, school, hall, and commercial centers alongside small-scaled agro-processing units are also considered. Table 3 gives the summary of estimated demand for wet and dry seasons.

Table 2: Electricity Load Requirement for Hypothetical Village in Nigeria

Load Description	Wet Season (March–October) Watt-hrs/day	Dry Season (November-February) Watt-hrs/day
LOAD TYPE A		
a. Domestic Load	76,500	79,500
b. School	1,360	1,480
c. Clinic	7,120	9,760
LOAD TYPE B		
a. Community Hall/ Infrastructure	3,280	3,300
b. Industrial, Agric. & Comm. Load	46,974	76,351
c. Miscellaneous Load	600	600
Overall Load Requirement	**135,834**	**170,991**

Load Sketch for Load A



Load sketch for Load B

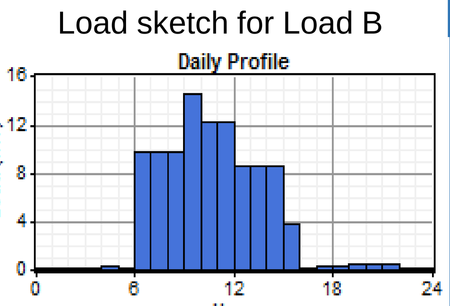


Table 3: Cost of Hybrid system Components

Components	Capital Cost (US$/kW)	Replacement Cost (US$/kW)	O&M Cost (US$/kW-yr)
Hydro Turbine	30,000	25,000	2,000
Wind Turbine (G 1kW)	3,500	2,800	100
Solar PV (1kW)	2,500	2,000	10
Generator (1kW)	250	200	0.25/hr
Battery	1,170	800	50
Converter	700	550	100

Result

In a bid to ascertain the optimal hybrid option in selected locations Nigeria, the Net Present Cost (NPC) and cost of electricity (COE) metrics are used and the result is tabulated below:

Table 4.: Best Hybrid System Configuration for Six Geopolitical Zones in Nigeria

		Balanga (NE)	Kabomo (NW)	Asa Dam (NC)	Edukwu (SE)	Elemi (SW)	Ibrede (SS)
PV	kW	9	**12**	9	3	9	**3**
Wind	kW	0	**0**	0	0	0	**0**
Hydro	kW	33.1	**36.8**	34.9	38.6	27.6	**28.0**
Diesel Generator	kW	12.5	**12.5**	12.5	12.5	12.5	**15.0**
Battery	no.	16	**16**	16	16	16	**16**
Converter	kW	10	**10**	10	10	10	**10**
Total Capital Cost	$	91,345	**103,845**	91,345	76,345	91,345	**76,970**
Total NPC	$	317,077	**326,567**	260,534	251,877	297,360	**237,362**
COE	$/kWh	0.479	**0.494**	0.394	0.381	0.450	**0.359**

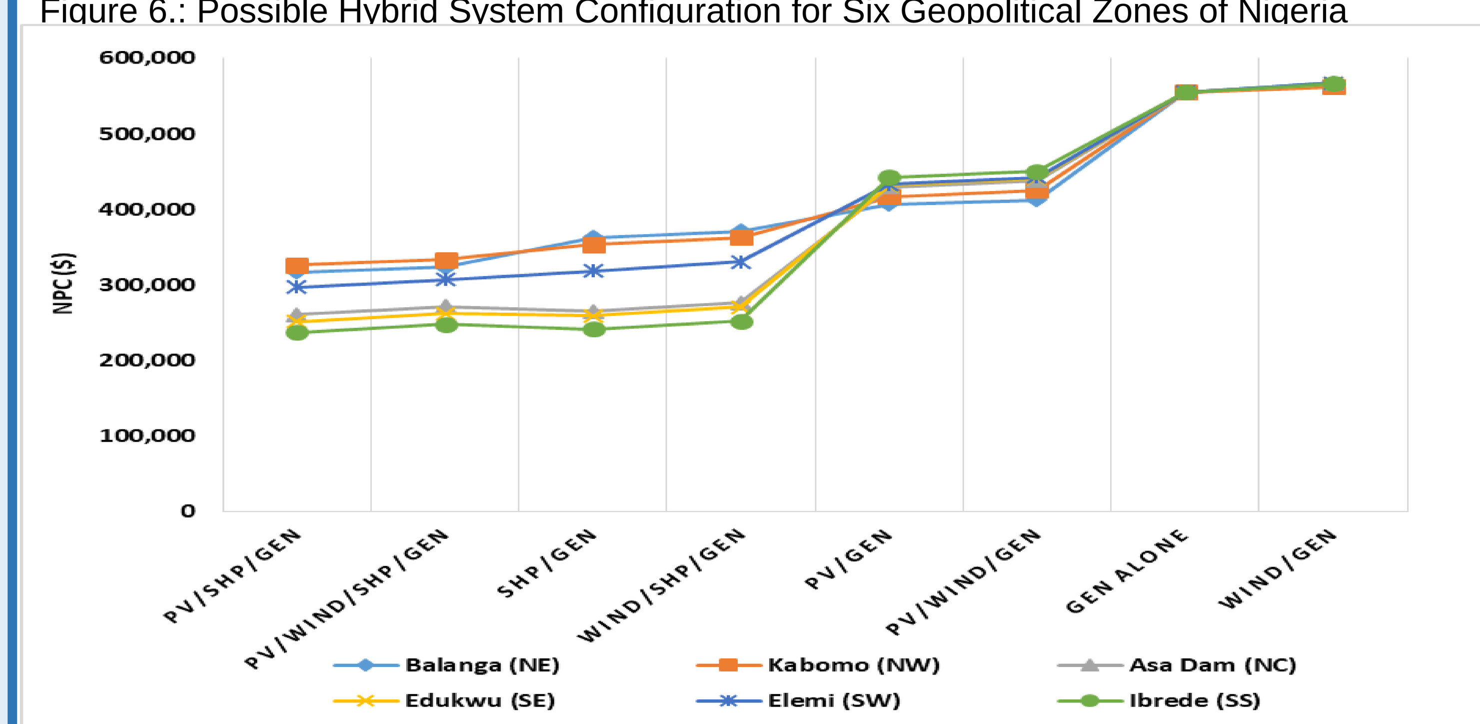
From the result, the most cost-effective configuration in all cases falls within the **PV/hydro/generator/battery** design.

The proposed system configuration gives the highest and lowest capital cost, NPC and COE respectively in Kabomo (NW) and Ibrede (SS).

Wind turbine is not chosen by HOMER for any of the sites owing to the weak average wind speed and high capital outlay

Synopsis of Possible hybrid system setups and Cost Implication

Figure 6.: Possible Hybrid System Configuration for Six Geopolitical Zones of Nigeria



Aside PV/SHP/Gen being the optimal design, PV/wind/SHP/Gen, SHP/Gen, wind/SHP/Gen, PV/Gen, PV/Wind/Gen constitute other feasible solution for implementation in the selected sites.

Nonetheless, the last two might require government incentive and support mechanisms to be attractive to investors

Environmental Emissions of Feasible Hybrid Configurations

Table 5: Comparison of Environmental Emissions from various hybrid Configurations

	Emission Kg/yr					
	CO_2	CO	UHC	PM	SO_2	NO_x
PV/SHP/Gen	20,010	49	5	4	40	441
SHP/Gen	27,088	67	7	5	54	597
PV/Wind/SHP/Gen	**14,211**	**35**	**4**	**3**	**29**	**313**
Wind/SHP/Gen	26,828	66	7	5	54	591
PV/Gen	30,740	76	8	6	62	677
PV/Wind/Gen	30,023	74	8	6	60	661
Gen Alone	**59,130**	**146**	**16**	**11**	**119**	**1,302**
Wind/Gen	58,474	144	16	11	117	1,288

PV/Wind/SHP/Gen provides the least pollutant emission as against the optimum configuration (PV/SHP/Gen)

The highest volume of pollutant emissions occurred in standalone diesel generator (3 times higher than that of the proposed optimal hybrid setup)

Conclusions

- Based on the above analysis, it can be concluded that a hybrid configuration system comprising SHP, PV, and Generator constitutes the most cost-effective option for off-grid rural electricity supply across Nigeria's six geopolitical zones.
- The NPC and LCOE metrics also reveal PV/wind/SHP/Gen, SHP/Gen, wind/SHP/Gen, PV/Gen as other possible options
- Finally, the suggested hybrid configuration represents a veritable route to curtail Nigeria’s lingering electricity crisis and reduce greenhouse gas emissions.