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


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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 is electrified thus leaving 70% of the rural population without electricity access
- To address this situation, this study attempts to develop hybrid configuration for rural electricity generation in each of the six geopolitical zones of Nigeria.

### 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:

Table1: 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 | 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" |

### Energy Potential Assessment at Six Selected locations in Nigeria

Figure 1: Calibrated hydro Flow Profile

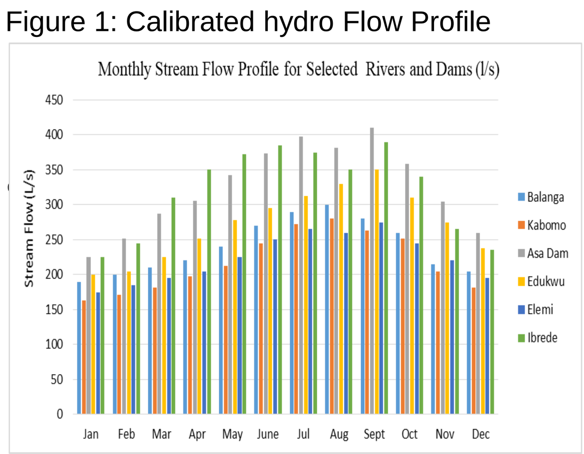



Figure 2: Solar Radiation Profile

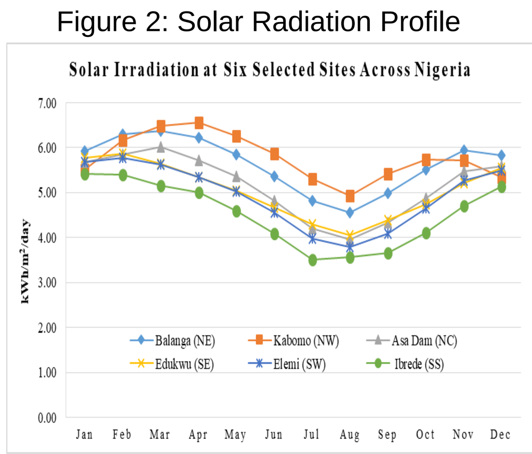
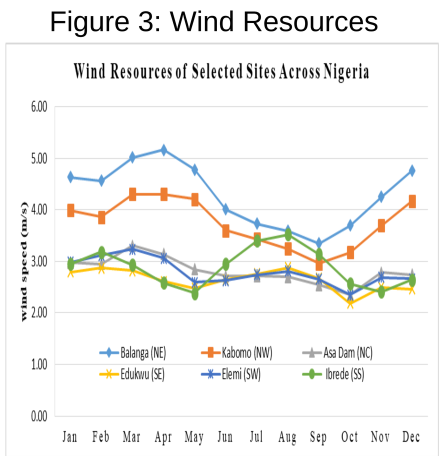



Figure 3: Wind Resources




## 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 back-up are considered (see Figure 4).

Figure 4: Schematic system configuration

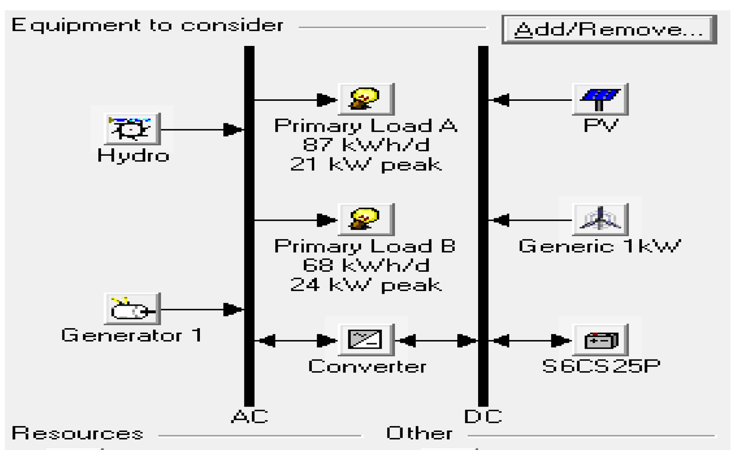
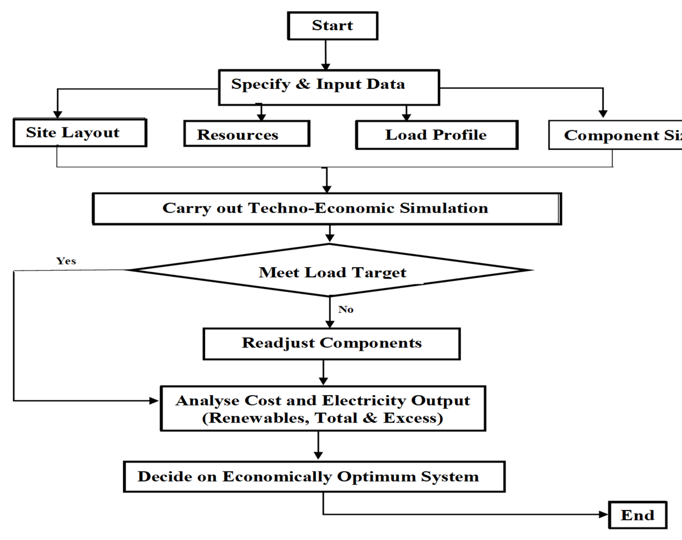



Figure 5: Framework of analysis



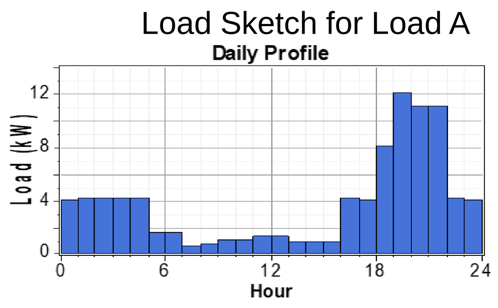

### Village Load Profile

- A hypothetical remote/rural community of 50 households comprising of about 400 to 500 people. A community clinic, school, hall, commercial centres 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

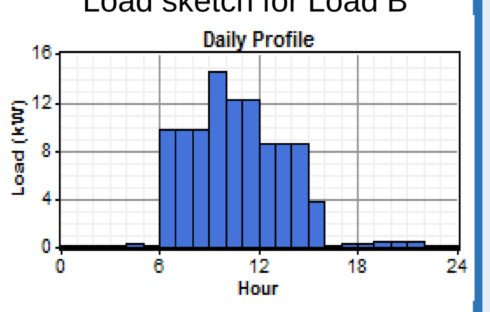



Table 3: Cost of Hybrid system Components

| 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** |

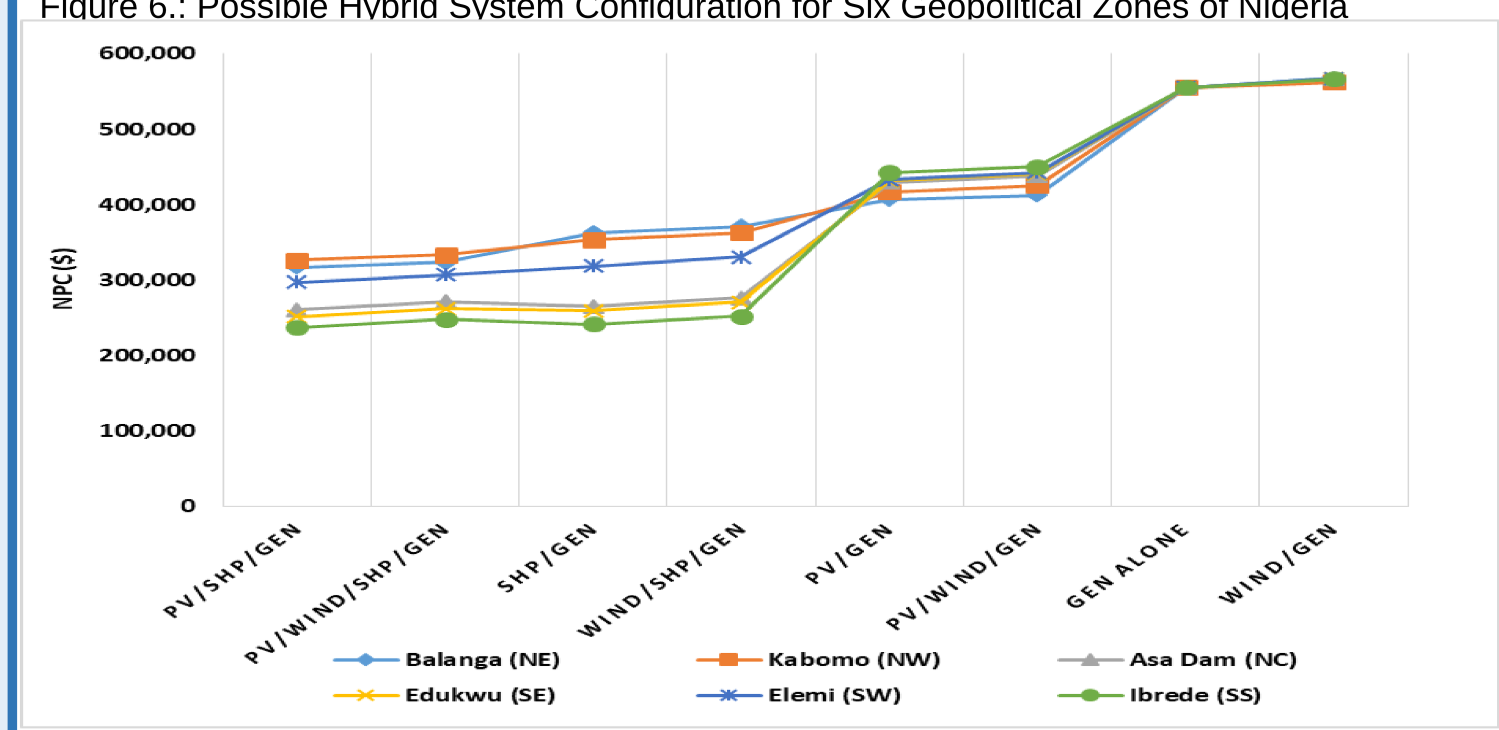
From the result, the most cost-effective configuration in all cases falls within the **PV/hydro/generator/battery** design.

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

- With the above analysis, it can be concluded that a hybrid configuration system comprising of SHP, PV and Generator constitutes the most cost effective option for off-grid rural electricity supply across the six geopolitical zones of Nigeria.
- 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.