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Evaluation of Mini-Grid Technology, Policy and Regulatory Framework in Nigeria

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Abstract:
The NERC 2016 Mini-grid regulations since coming into force has received very little academic attention. This paper provides an evaluation of mini-grid technology, policy and regulatory framework in Nigeria using NERC classification. The study utilized one primary study area (Aba-Gbooro), and 37 secondary locations, one in each of the 36 states of the Federation and one in the Federal Capital Territory (FCT). Two load profile scenarios were considered: the base case load and a second scenario that incorporated Anchor and Business load at the same peak load. The paper utilized HOMER for the simulation using Solar PV (PV)), Diesel Generator(G), Storage Battery(B), Converter (C) and Hydro (H). The Hybrid of PV+G+B+C architecture was recommended for 25 states while for 11 states with mini hydro (H) potential, hybrid of PV+G+B+C+H was recommended for few locations with hydro potentials. The LCOE for the PV+G+B+C at 25% interest rate was $0.481, higher than for the PV+G+B+C+H with LCOE of $0.302 for the same load profile. The LCOE was also found to be higher at higher interest rates. Renewable energy (RE) penetration also increased with lower interest rates. Subsidy as high as 75% (on capital costs only) did not lead to tariff parity with the grid. The paper then made a case for feed-in tariff as a complementary policy to increase investment in mini-grid and increase RE penetration. Anchor and Business load gave rise to increase in the load factor from 0.4 to 0.86 and resulted in lower LCOE compared to the base case. This suggests stronger SME initiative support in the rural areas is germane for mini-grid development.

Keywords: *Mini-grid,Feed-in tariff, LCOE, Global Horizontal Irradiation (GHI), wind speed*

1. Introduction

The issues plaguing the Nigerian Electricity Supply Industry (NESI) are not limited to poor access especially in the rural areas but also reliability and quality of supply in the areas with grid-tied electricity supply.

More than 75 Million Nigerians live without access to electricity. About 70% of these reside in the rural areas of the country. Besides, poor access, reliability and quality issues abound in different degrees in the areas with electricity access [1]. About 33 power outages per month and an average of 12 hours of no supply per day.

Mini-grids (or microgrid in some domain) are gaining increasing recognition both in developing and developed countries as viable solution to mostly energy access but also reliability and resilience [2-11, 14]. In general, solution to energy access problems in most developing countries usually revolve around: Solar Home Systems (SHS), Mini-grids and grid extension to unconnected areas [2]. According to a recent report, In Nigeria, Mini-grid is deemed the most appropriate energy accesssolution for only about 13.6 Million persons, SHS for another 6.2 Million and grid extension for about 86.2 Million persons within 15km radius of the grid. This is depicted in Figure 1 [2]. This kind of assertion requires careful study as many of these remote locations do not have sufficient economic activities and sufficient customers willing and able to pay for electricity to justify investment by the Distribution Companies (DISCOS) who are already on the verge of collapsing under huge burden of very high technical and commercial loses. SHS is also not without its own challenges including limitation regarding its suitability for productive use of energy (PUE), sustainability and quality control problems [12]. Mini-grid has been reported by many authors as a viable solution to bridging the supply gaps not only in Nigeria but in different parts of the globe. However, appropriate technology, policy and regulatory framework are crucial both to the success and sustainability of Mini-grids in Developing Countries [4].

Nigerian Electricity Regulations Commission (NERC) believes that Mini-grids can be a viable solution to energy access problems for persons living without electricity supply ('unserved') and those living poorly supplied areas ('underserved'). Based on this, the NERC came up with a regulation to promote mini-grids and set guidelines for how they will relate with and operate within the jurisdiction of the Distribution Licensees who ordinarily should have exclusive jurisdictions to distribute electricity within their assigned areas [13].

This regulation has made some impacts in terms of mini-grid development in Nigeria leading to improved participation in this sector by private independent mini-grid developers who now see opportunities to operate mini-grids as services and a business concern as a result of the clarity provided by the regulations.

One of the aims of the Nigerian government is to scale up the mini-grid capacity from 50 MWh based on 2016 figures to about 5,314 MWh in 2030[2]. This shows clearly that development in this sector is still in the formative stages, where stakeholders and researchers are needed to contribute to improvement of policy and regulatory framework for mini-grids to thrive.

Despite this regulation, mini-grid development in Nigeria is still slow and facing a number of challenges today. Many of the developers try to stay as far away as possible from the grid based on the assumption that no DISCO has any plan of grid extension to location further than 5km in the next 5 – 10 years. Some of the challenges hampering the proliferation and advancement of mini-grids in Nigeria include lack of access to finance, know-how and capacity shortage of stakeholders, availability of market information and data, policy and regulatory framework and proven business models [2].

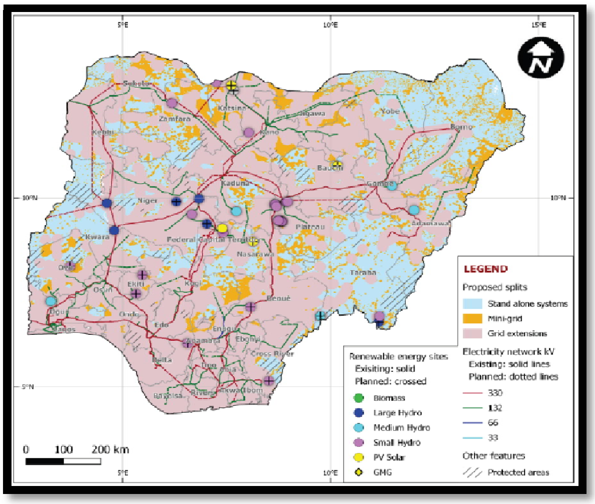

Figure 1: Mini-Grid, Grid Extension andStand Alone Potential
Source: ECOWREX Database Portal, Carbon Trust Analysis

2. Scope of the Study and Description of the Study Areas

2.1. Scope and Justification of the Study

Although the NERC Mini-grid Regulation of 2016 covers both the unserved and underserved areas, the scope of this study is restricted to the unserved area because the scope and extent of work for both unserved and underserved areas are big enough on their own to stand alone and each require different research approaches and methodologies difficult to combine without confusing the readers of the paper.

Mini-grid and discussion around its development are becoming trendy and topical in Nigeria and justified by the huge energy access and reliability issues thereby requiring more studies to enhance its development.

The NERC mini-grid regulations since becoming operational has not benefited so much from academically biased intensive evaluation, criticism and assessment to highlight the key areas that should be improved and other critical policy directions and regulations that must be introduced contemporaneously to achieve the desired outcomes. This is the main aim of this research.

In achieving the above aim, this paper provides insight into the applicable technologies for mini-grids across the 36 States of the federation based on primary energy resources available in these states, which provides a baselines information for intending mini-grid developers. The methodology used in determining the load profile for the primary study area is very pragmatic, novel and better exemplified compared to other studies and can be adopted by other researchers and mini-grid developers. The paper unlike other studies utilized concepts of willingness and ability to pay measurement into needs assessment and requirements for mini-grid development. Complementary policies for successful mini-grid development were also evaluated and demonstrated using empirical analysis, which can aid policy formulation by NERC. The study also provides some macroeconomic dimension to mini-grid development by putting forward arguments for reduction in the interest rate for loans to mini-grid developers to between 10-15%.

The study provides quantitative inputs into the impacts of different level of subsidy on sustainability of mini-grids and makes a case for implementation of feed-in tariffs for mini-grid developers in Nigeria. Lastly the study highlights the relationship between low interest rates and renewable energy penetration and shows further how mini-grid with appropriate policies can contribute to reduction in Green House Gases (GHG), particulate maters and other pollutants in Nigeria.

2.2. Description of the Study Areas

2.2.1. Primary Study Area

The primary study area for this research is a village named 'Aba Gbooro' located at Latitude 7°32.7´N and Longitude 4°29.5´E. The aerial view of the village is presented in Figure 2 below.

Figure 2: Aerial View of the Primary Study Area, Aba-Gbooro Village (Google Earth)

The Village falls under the NERC mini-grid regulation as 'unserved' without access to grid. There is no electricity distribution infrastructure in the village. The total population of the village is 296 inhabitants with an average of 6.6 persons per household many of whom have stayed there for more than 2 decades. The total number of households is 45. The demographics for the village are given in Table 1.0. The predominant occupation of the inhabitants is farming majorly on subsistence level. The crops grown in this village include yam, maize, cassava, pepper, tomatoes, plantain, banana, etc with fewer persons involved in growing cash crops like cocoa. There is very little productive use of energy (PUE) within the village except for 1 Gari processing centre utilizing Leicester Engine of about 10KVA for grinding cassava.

Data for Aba Gbooro Village	
Demographics	
Total No of Adult Male	48
Total No of Adult Female	67
Total Number of Children	181
Occupation	
Total Number of Farmers	103
Total Number of Petty Traders	8
Total Number of Civil Servants	1
Others	3
Ownership & Use of Buildings	
No of Owned Buildings	39
No of Rented Buildings	6
Average Rent per month	₦600
No of Residential Buildings	39
No of buildings used for Business / PUE	3
Buildings used for religious purposes	3

Table 1: Demographics, Occupation and Building Usage Data

Figure 3: A Typical Agro-Processing (Gari) Outifit At Aba Gbooro Village

The villagers have made several attempts to get connected to the grid about 6km away through self-help means via contributions by levying members of the community. However, before the extension could be completed, the installation was vandalized and the cables were carted away, thereby frustrating the effort. This puts in question the pragmatism of the assumption that grid extension can be the best strategy for locations within 15 Km of the grid, spanning kilometres of areas uninhabited and poor electricity supply which makes pilfering of the infrastructures especially cables very easy.

Baseline Energy Utilization & Onsite Electricity Generation	
No of Household using Kerosene lamps	11
No of Households with local lamp (using palm oil)	1
No of Households using Kerosene for cooking partially	11
Average spend per month for such households	₦2,493
No of households using gas cooker for cooking	1
Average spend per month for such households	₦3,000
No of households with onsite generation of electricity - Petrol	7
Average spend on petrol per month per household	₦3,120
No of households/businesses with onsite generation of electricity - / diesel	2
Average spend on diesel per month per household.	₦15,000
Primary Purpose of energy utilization	lighting, cooking, phone charging and appliances.
Baseline Appliance Endowment	
No of Households with Standing Fans	3
No of Households with rechargeable lamps	28
No of Household with Radio	8
No of Household with TV	6
No of Household with electrical Wiring and Incandescent bulb	7
Total Number of phones in the village	111
Others	1
Current means of Charging the Phone	In town / with neighbors with generators

Table 2: Energy Utilization Baseline and Appliance Endowment

The choices of Aba-Gbooro was not only because it is a perfect fit into NERC's definition of an unserved area but also because it is representative of the large majority ofremote and very poor agrarian communities, where both abilitiy to pay (connected with household income) much more than willingness to pay (connected price and value - affordability) is a problem. The vast majority of people to be given access to electricity fall in this category. Moderately finacially confortable house in remote areas using generator fairly regularly for lighting and basic appliances or villages where there is high PUE activities already has an energy bill higher than grid-based supply for the same level of consumption. For example, 1.5hp engineconsuming about 0.3 litres per hour at an average of 6 hours utilization per day will consume equivalent of 55.8 L per month costing over 8,000 naira of petrol per month. The key indicators of energy utilization, income, economic and productive activities, onsite generation, baseline appliance endowment and energy utilization are presented in Table 2 .

Figure 4: A Typical Household at Aba Gbooro Village

Although, the inhabitants are poor but nothing will satisfy them but electricity supply which allows them to buy and utilize appliances. The villagers are very open to the idea of a private run mini-grid to supply electricity to the village. Energy utilization for businesses and productive use is very minimal in the village. Only 1 barbing salon, agro-processing outfit shown in Figure 3, a cocoa store and a beer parlor. The the minimum monthly wind speed is 2.41 m/s while the maximum for this location is 3.35 maximum with an average of 2.87 m/s. The minimum monthly Global Horizontal Irradiance (GHI) is 3.73 KWh/m2/day while the maximium GHI is 5.74 KWh/m2/day with an average of 4.89 KWh/m2/day. The location does not have potential for mini hydro plant even though Osun State in general has a potential for some mini-ydro plants in few locations.

2.2.2. Secondary Study Areas

The secondary study areas covered include random locations within the perimeter of every of the 36 states of the Federation. One location per state was selected for this study and all together we have 37 locations which were used in the simulation. The details of the location including the longitude and latitudes, minimum and maximum wind speed in m/s and solar Global Horizontal Irradiance (GHI) are presented in Table 3 based on geopolitical zones depicting the potential of each of the location of a hybrid mini-grid.

The national minimum monthly wind speed is 2.16 m/s from the South South (Cross River) and it occurs around October/September while the maxium is 5.83 m/s from the North East zone (Borno) occuring around March/April. The national minimum GHI is 3.73 KWh/m2/day from the South West geopolitical zone and occuring in the month of August while the national maximum GHI is 7.21 KWh/m2/day from the North West geopolitical zone and occuring in the month of March. Generally, there appears to be more abundant solar irradation in the country than wind resources. However, some locations in the North East and North West subject to more detailed wind resource assessment appear to show some promises for hybrid mini-grid incorporating wind urbines as part of the configuration if the economics support it.

3. Methods and Tools

3.1. Geolocation of the study areas using GIS tools and preliminary assessment

Preliminary assessment of suitable locations was carried out to assess whether it falls under the category of unserved areas as per NERC 2016 mini-grid regulations.A very popular GIS tool, Google Earth was used to carry out desktop evaluation of the location and mapping out the entire Aba Gbooro village preparatory to site assessment and survey.

Following the location mapping and acquisition of geolocation data, Site visit and assessment were carried out to tag and number the households in preparation for electricity demand survey.

Zone	States	Wind Speed (m/s)		Solar GHI (KWh/m2/day)	
		Min (Month)	Max (Month)	Min	Max
NC	Benue, Kogi, Kwara, Nasarawa, Plateau, Niger & FCT	2.44	3.86	3.95	6.27
		Oct & Sep	Mar & Apr	Aug	Mar
NE	Adamawa, Bauchi, Borno, Gombe, Taraba, Yobe	3.18	5.83	4.43	6.78
		Oct & Sep	Mar & Apr	Aug	Mar
NW	Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto& Zamfara	2.43	5.01	4.47	7.21
		Oct & Sep	Mar, Apr & May	Aug & Dec	Mar
SE	Abia, Anambra, Ebonyi, Enugu & Imo	2.17	4.13	3.77	5.86
		Oct, Sep, May	Mar, Apr & Aug	Aug	Feb & Mar
SS	Akwa Ibom, Bayelsa, Cross-River, Delta, Edo & Rivers	2.16	4.66	3.82	5.7
		Oct & Sep	Mar & Apr	Aug	Mar
SW	Ekiti, Lagos, Ogun, Ondo, Osun & Oyo	2.35	3.49	3.73	5.77
		Oct & Sep	Mar & Apr	Aug	Mar

Table 3: Wind Speed and Solar GHI for 36 States ofthe Federation by Geopolitical Zones (Source: Authors' Compilation from NASA Database)

3.2. Input Data Types and Sourcing

Multiplicity of data from different sources were utilized in this study including primary data obtained from survey such as nature of inhabitants of the village, demography, occupation, baseline energy utilization studies were carried out to obtain: information on energy bill of each household, current energy utilization by type, Income data, indicators of willingness and ability to pay, occupancy pattern, current appliance endowment and forecast, time of use (ToU) for each household, etc. These are very critical data required to achieve bottom-up estimation of the load demand for the village.

Other secondary data utilized include the macro economic data like the interest rate for the month of October 2019, inflation rate for the month of October 2019 sourced from Central Bank of Nigeria (CBN). Solar Global Horizontal Irradiance (GHI) data for the primary location and 37 other locations one in each state of the Federation were compiled by the authors from NASA and NREL databases. Cost of components utilized are based on the cost of standard components in HOMER which is based on cost information and data from the vendors and Original equipment manufacturers and are therefore more reliable.

3.3. Survey Design and Critical Consideration for Successful Deployments

For a typical agrarian community with very high illiteracy rate and initial scepticism on the part of the inhabitants, obtaining accurate data required good understanding of the local language and culture. Geolocation and mapping using GIS tools earlier described under section 3.1 is a very critical tool for successful deployment of the surveys. Involvement of the leaders of the community proved very useful in getting the required cooperation from respondents.

3.4. Load Demand Estimation – Bottom up Estimation Approach

Load demand estimation to arrive at the loaf profile and the peak load for the village was carried out using the bottom-up estimation approach, which entails a build-up of the household demand from the appliance endowment for the household multiplied by the availability factor derived from the occupancy pattern to arrive at the hourly demand for the household and ultimately the daily household demand. This approach is different from the methodology by other researchers who have either employed the use of scenarios for building load demand for a given location or even used synthetic load thereby reducing the reliability of the results of such studies. The households demands were then aggregated and rolled up to determine the load profile of the entire village.

Many studies and reports utilized current energy demand or appliance endowment for remote areas to evaluate the load demand for the area or determine the energy access initiative to deploy to a particulararea. This practise is usually very erroneous and often produces unrealistic load profile.

In this paper, the baseline appliance endowment utilized was obtained from a combination of factors such as current energy bill on kerosene for lighting and cooking, number of rechargeable lamps, income indicator, amount spent by the household for onsite generation of electricity for petrol and diesel to categorize consumers and appliances were assigned based on the categories and the availability factor was applied to the appliances using the occupancy details. This produced a more realistic load profile, which is neither over or underestimated. A factor of 20% was applied to the load profile to account for boom time effect, which is a phenomenal that results in increased energy utilization coming from new households within a particular locality as a result of influx of new inhabitants or improvement in the standard of living of current households leading to acquisition of more appliances.

The consumer categorization based on forecasted load using a combination of different factors like: size of the household, occupancy pattern, amount consumers are willing and able to pay and in the design is presented in Table 4. The same philosophy is very useful in tariff design with respect to cross-subsidization between the different categories of consumers. The pie chart showing the distribution of the different categories of consumers is presented in Figure 5.

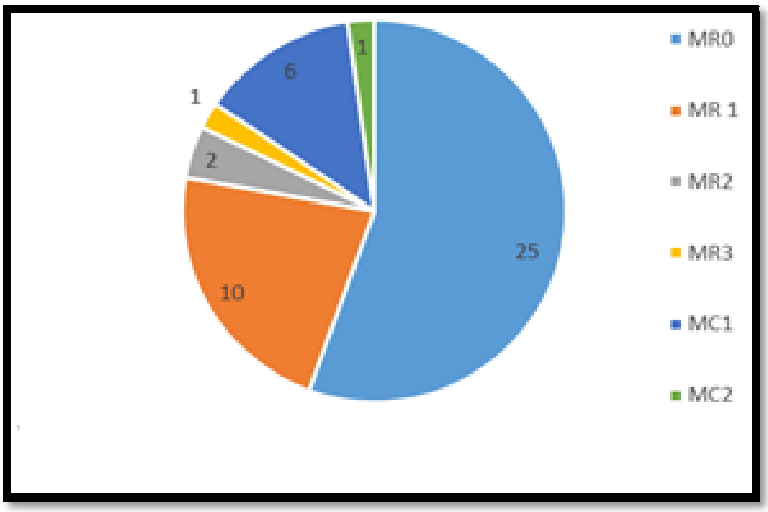

Figure 5: Distribution of Consumers by on Consumption Categorization

Based on the pie chart from Figure 4 the class MR0 is in the majority by about 57% of the entire households belonging to individuals utilizing maximum of 1 KWhr per day. Followed by MR1 – 22%, corresponding to households utilizing maximum of 2 KWhr per day. MC1 which corresponds to the class of consumers who are into businesses or utilising electricity for purposes other than residential including churches is 13 %. This category utilizes about 200 KWhr per month.

3.5.Mini-Grid Design Optimization and Sensitivity Analysis Using HOMER

Hybrid Optimization Model for Electric Renewables (HOMER) was utilized for the design and the simulation of the mini-grids for both the primary study area and the secondary study areas. The load profile obtained from the primary study area was used for simulation for all the secondary location presented in Table 7 and the recommended mini-grid architecture and configuration was reported under the 2nd to the last column of the table. The components and resources utilized are presented in Figures 5 and 6. The first configuration considers a hybrid of Solar PV, Diesel generator, Wind Turbine and storage batteries.

For this configuration, the wind resource data and solar GHI presented in Table 7 were the primary energy resources considered. The second configuration on the other hand considers hybrid of solar PV, Diesel generator, Wind Turbine, Mini-hydro and storage batteries in the simulation. This was used for locations where solar mini hydro resources exist in the country. The simulation results are presented and discussed under section 4 of this paper.

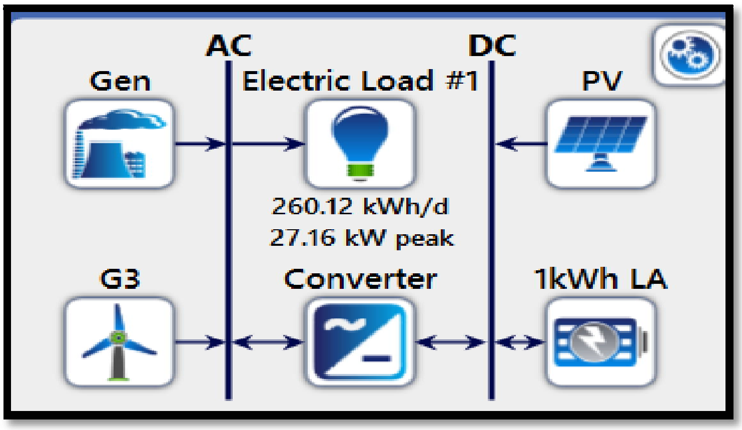

Figure 6: Schematic Solar PV, Diesel Generator, and Wind Turbine and Storage Batteries Configuration

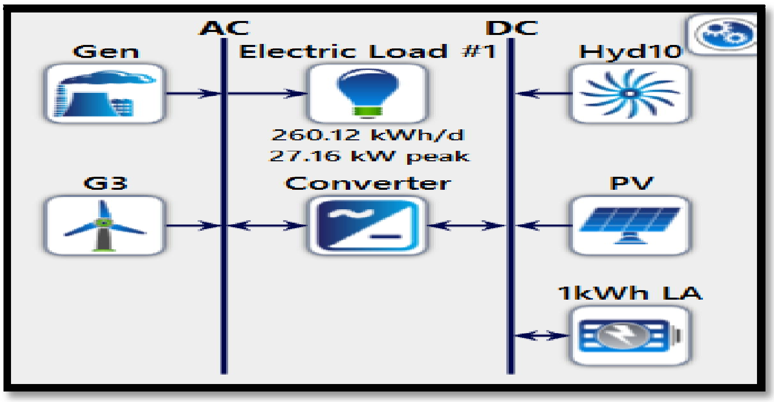

Figure 7: Schematic Solar PV, Diesel Generator, Wind Turbine, Mini-Hydro and Storage Batteries Configuration

4. Results and Discussions

4.1 Load Profiles

Two load profiles scenarios were utilized in the modelling:

- Load profile for the base case: This is based on the actual load data gathered from the primary survey area without any alteration. This is presented in Figure 8 and Table 5
- Load Profile for the addition of Anchor Load and Business Load: This is based on modification of the base case by addition of the following Anchor and Business Case Load:

Inclusion of Small Sachet water production factory with a peak load of 11 KW and operating from 11:00 p.m. to 8:00 a.m. in the morning.

Introduction of an agro processing hub for the village with a peak load of 25 KWoperating from 8:00 a.m. to 2 p.m. in the afternoon. This agro processing hub shall utilize modern designs for water conservations and energy saving equipment throughout the entire value chain from grinding, pressing to drying and packaging of the end product. This is presented in Figures and Table 6

Classification Code	Criteria / Basis of Classification	Appliances Included in Load Demand	Maximum Daily forecasted demand
Residential – MR0		Electric Bulbs	
	Requirement for lighting only and telephone charging only. Able to pay maximum of 2,000 Naira only Current energy bill for kerosene less than 1,000 naira.	Phone Charging	Maximum of 1KWhr per day.
Residential - MR1	Requirements for Lighting, telephone charging, Radio & TV. Able to Pay less than 4,000 Naira per month Current energy bill for kerosene up to 2,000 naira per month.	Electric bulbs Phone Charging Radio Small TV	Maximum of 2 KWhr per day
Residential - MR2	Requirement for Lighting, telephone charging and other light appliances: Able to pay between 4,000 and 8,000 Naira per month. Current energy bill for kerosene more than 2,00 naira.	Electric Bulbs TV Phone Charging Radio Fans Small Fridge/Freezer	Maximum of 4 KWhr per day
Residential - MR3	Requirement for Lighting, telephone charging and other basic Household appliances. Able to pay between more than 8,000 Naira per month. Currently involved in onsite electricity generation.	Electric Bulbs TV and DSTV Decoder Phone Charging Pressing iron Kitchen appliances Radio fans Small Fridge Freezer Washing Machine laptops Water Dispenser ACs etc.	8 KWhr and above per day
Commercial – MC1	Business Environment Utilization of Appliances other than household equipment for business or religious purposes Able to pay between 5,000 and 10,000 per month.	Include light appliances and equipment for business purposes. Church or mosque equipment like amplifiers, speakers, microphone, lighting, fans, etc.	About 200 KWhr per month.
Commercial – MC2	Business Environment Utilization of heavy industrial appliance including Agro-processing equipment for commercial purposes Able to pay more than 10,000 per month. Involved in Onsite Electricity Generation	Include heavy industrial appliances for business purposes Agro-processing equipment and venture.	More than 200 KWhr per month.

Table 4: Consumption Categorization

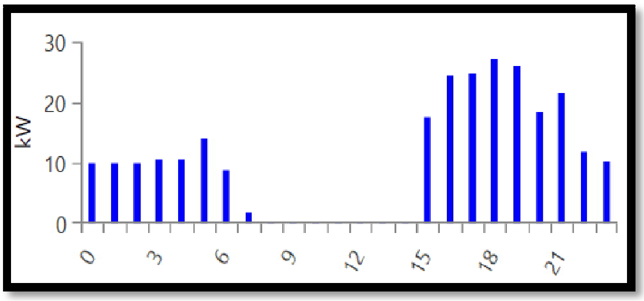

Figure 8: Base Case Daily Load Profile

Metric	Baseline	Scaled
Average (kWh/day)	260.12	260.12
Average(kW)	10.84	10.84
Peak (kW)	27.16	27.16
Load factor	.4	.4

Table 5: Base Case Peak Loads and Load Factor

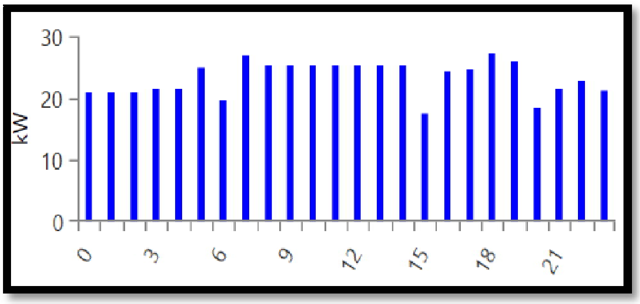

Figure 9:Daily Load Profile for Anchor Load &Business Load Case

Metric	Baseline	Scaled
Average (kWh/day)	559.12	559.12
Average(kW)	23.3	23.3
Peak (kW)	27.16	27.16
Load factor	.86	.86

Table 6: Anchor and Business Load Case Peak Load and Load Factor

From the load profiles for the 2 scenarios, the peak load remains 27.16 KW for both the base case and Anchor and Business Loads (ABL) case. However, the Load factor increase from 0.4 for the base case to 0.86 for the ABL case leading to more than double of the average daily load for the ABL case of about 559.12 KWh/day.

4.2 Hybrid Mini-Grid Architecture Recommended for Different States

The hybrid mini-grid configuration recommended after our simulation for the different states of the Federation for the 37 secondary locations used in the simulation are presented in Table 7.

Hybrid configuration which comes highly recommended for all the locations across the 36

States of the federation and the Federal Capital Territory (FCT) Abuja is the Solar PV (PV), Diesel Generator (G), Storage Battery (B) and Converter (C). Wind turbine was not recommended from the simulation. This is not unexpected because the wind speed across the Country does not support utility scale electricity generation for most part of the country except for few locations in the North East and North West Region that show some promises for wind resource but will require more detailed resource assessment to ascertain their feasibility.

For Certain states like Osun, Oyo, Ogun, Ekiti, Niger, Anambra, Cross-River, Ondo, Taraba, Edo and Benue that have some proven micro and mini hydro potentials at some selected locations, Solar PV (PV), Diesel Generator (G), Storage Battery (B), Converter (C) and Hydro (H) was the recommend configuration. However, for other parts of these states that do not have the hydro potential, Hybrid of PV, G, B and C was recommended.

The HOMER simulation tool utilized the Net Present Cost (NPC) to rank several possible configurations using the resources (hydro (head and flow rate), Solar GHI, Diesel fuel cost, wind speed, etc), component costs, interest rates, project life cycle, inflation rate, and other input variables. For the PV+G+B+C configuration, the lowest LCOE recorded was $0.44 at 10% interest rate while at higher interest rates of 25%, which is the most realistic in Nigeria, the LCOE increased to $ 0.481. In contrast, the LCOE at 10% interest rate for the PV+G+B+C+H was $0.181 while at higher interest rate, LCOE increased to $ 0. 302 which is still lower than what PV+G+B+C gave for the same load profile.

4.3 Effect of Subsidy on Mini-grid Economics

The effect of introduction of subsidy at 10%, 15%, 20% and 25% interest rates was modelled for the primary study area. Subsidy was applied to the initial capital costs and capital replacement cost only for both the base case and the anchor and business case scenarios. The results of the simulation for Levelized Cost of Energy (LCOE) and Renewable Energy Fraction (Ren Fraction) are presented in Tables 8 & 9.

The following were deduced from the result of the simulation presented in Tables 8 and 9.

- The LCOE for the Anchor load and the business case scenario were generally lower than for the base case scenario at same interest rates and same subsidy level. This is because introduction of Anchor Load and Business load gave rise to higher load factor.
- Generally, increase in the subsidy yielded increase in renewable energy penetration depicted by Renewable Energy factor (Ren. Factor). This may suggest that reduction of carbon emission for activities related to electricity generation responds very well to subsidy introduction for the initial capital and replacement costs.
- Increase in interest rates lead to increase in LCOE due to higher cost of capital at higher interest rates compared to lower rates.

4.4 Tariff Parity between Utility Grid and Mini-Grid

The lowest LCOE of $0.154 per KWhr of electricity occurred in the Anchor and Business Load scenario at 75% subsidy while the highest LCOE of $0.48 per KWhr of electricity occurred at the Base Case with very low anchor/business load at 0% subsidy level.

Even with subsidy and anchor and business load introduction, tariff parity still could not be achieved for mini-grid. The tariff per KWhr of electricity in Nigeria is about 32 Naira equivalence of $ 0.105 per KWhr @ exchange rate of 306 Naira to $ 1.

4.5 Case for Feed-in Tariff for Mini-grid in Nigeria

The results of this paper showed that even at subsidy level on initial capital cost and replacement cost for the components of the mini-grid, tariff parity could not be achieved with the main utility grid tariff. The authors hereby make a case for feed-in tariff for renewable energy penetration per KWhr for Solar, hydro and wind turbine.

S/N	Region	STATE	Latitude	Longitude	Potential for mini hydro plant		Wind Speed			Solar GHI			Mini-grid Architecture	
							Min	Max	Avg	Min	Max	Avg	Technology Configuration	Locations for Hydro Resources
1	North Central	Benue	7°44.3´N	8°32.0´E	Yes	Dam	2.71	3.52	3.24	4.19	6.01	5.19	PV + G + B + C+ H*	Awieke
2		FCT	9°3.7´N	7°31.2´E	No	N/A	2.58	3.23	3.01	4.19	6.27	5.45	PV + G + B + C	
3		Kogi	7°48.0´N	6°43.9´E	No	N/A	2.44	3.32	2.93	4.13	5.84	5.1	PV + G + B + C	
4		Kwara	8°28.7´N	4°34.9´E	No	N/A	2.35	3.3	2.81	3.95	6.02	5.16	PV + G + B + C	

S/N		STATE	Latitude	Longitude	Potential for mini hydro plant		Wind Speed			Solar GHI			Mini-grid Architecture	
							Min	Max	Avg	Min	Max	Avg	Technology Configuration	Locations for Hydro Resources
5		Nassarawa	8°30.6´N	8°32.6´E	No	N/A	2.97	3.77	3.51	4.28	6.15	5.37	PV + G + B + C	
6		Plateau	9°51.0´N	8°53.8´E	No	N/A	2.97	3.86	3.46	4.21	6.35	5.47	PV + G + B + C	
7		Niger	9°37.8´N	6°32.2´E	Yes	Dam & River	2.51	3.27	2.95	4.36	6.26	5.49	PV + G + B + C+ H*	Tagwai, Mfum, Baata
8	North East	Adamawa	9°12.2´N	12°29.7´E	No	N/A	3.41	5.31	4.4	4.79	6.41	5.7	PV + G + B + C	
9		Bauchi	10°18.4´N	9°48.7´E	No	N/A	3.18	4.77	4.04	4.95	6.4	5.77	PV + G + B + C	
10		Borno	11°49.2´N	13°9.4´E	No	N/A	3.62	5.83	4.8	5.14	6.7	5.9	PV + G + B + C	
11		Gombe	10°16.9´N	11°9.8´E	No	N/A	3.41	5.34	4.44	5	6.45	5.77	PV + G + B + C	
12		Taraba	8°53.6´N	11°22.6´E	Yes	Dam	3.26	4.92	4.12	4.43	6.47	5.57	PV + G + B + C+ H*	

S/N		STATE	Latitude	Longitude	Potential for mini hydro plant		Wind Speed			Solar GHI			Mini-grid Architecture	
							Min	Max	Avg	Min	Max	Avg	Technology Configuration	Locations for Hydro Resources
13		Yobe	11°44.5´N	11°58.1´E	No	N/A	3.44	5.47	4.53	5.27	6.78	5.96	PV + G + B + C	
14	North West	Jigawa	11°44.8´N	9°20.6´E	No	N/A	3.23	5.01	4.23	5.3	6.67	5.9	PV + G + B + C	
15		Kaduna	10°31.4´N	7°26.5´E	No	N/A	2.72	3.59	3.19	4.47	6.32	5.65	PV + G + B + C	
16		Kano	11°59.0´N	8°33.1´E	No	N/A	3.09	4.66	3.98	5.16	6.69	5.87	PV + G + B + C	
17		Katsina	12°59.8´N	7°38.2´E	No	N/A	3.08	4.79	4.07	5.23	7.21	6.28	PV + G + B + C	
18		Kebbi	12°27.8´N	4°12.6´E	No	N/A	2.43	3.43	2.93	5.29	6.76	5.98	PV + G + B + C	
19		Sokoto	13°2.0´N	5°15.0´E	No	N/A	2.57	3.65	3.15	5.25	7.15	6.24	PV + G + B + C	
20		Zamfara	12°10.3´N	6°39.7´E	No	N/A	2.83	4.13	3.59	5.32	6.84	6.01	PV + G + B + C	
21	South East	Abia	5°31.5´N	7°29.2´E	No	N/A	2.23	3.37	2.7	3.77	5.59	4.71	PV + G + B + C	

S/N		STATE	Latitude	Longitude	Potential for mini hydro plant		Wind Speed			Solar GHI			Mini-grid Architecture	
							Min	Max	Avg	Min	Max	Avg	Technology Configuration	Locations for Hydro Resources
22		Anambra	6°14.2´N	7°5.9´E	Yes	River	2.17	3.13	2.64	3.91	5.4	4.93	PV + G + B + C+ H*	Onitsha
23		Ebonyi	6°19.6´N	8°6.3´E	No	N/A	2.18	2.88	2.64	4.06	5.86	5.05	PV + G + B + C	
24		Enugu	6°27.1´N	7°31.7´E	No	N/A	2.17	3.13	2.64	3.91	5.74	4.93	PV + G + B + C	
25		Imo	5°29.6´N	7°1.8´E	No	N/A	2.83	4.13	3.59	3.77	5.59	4.71	PV + G + B + C	
26	South South	Akwa Ibom	5°2.7´N	7°56.6´E	No	N/A	2.23	3.37	2.7	3.77	5.59	4.71	PV + G + B + C	
27		Bayelsa	4°56.0´N	6°16.6´E	No	N/A	2.65	4.66	3.45	3.11	5.24	4.13	PV + G + B + C	
28		Cross River	4°56.0´N	6°16.6´E	Yes	River	2.16	3.68	2.76	3.11	5.7	4.28	PV + G + B + C+ H*	Itu
29		Delta	6°12.4´N	6°41.8´E	No	N/A	2.29	3.08	2.71	3.82	5.6	4.81	PV + G + B + C	

S/N		STATE	Latitude	Longitude	Potential for mini hydro plant		Wind Speed			Solar GHI			Mini-grid Architecture	
							Min	Max	Avg	Min	Max	Avg	Technology Configuration	Locations for Hydro Resources
30		Edo	6°19.3´N	5°37.2´E	Yes	Run-off River	2.41	3.19	2.79	3.57	5.49	4.66	PV + G + B + C+ H*	Evboro II
31		Rivers	4°46.6´N	7°1.0´E	No	N/A	2.47	4.54	3.25	3.24	5.24	4.21	PV + G + B + C	
32	South West	Ekiti	7°37.6´N	5°12.9´E	Yes	Dam & River	2.35	3.23	2.79	3.78	5.77	4.94	PV + G + B + C+ H*	**Ekiti:**EffonAlaye, Ikun Ekiti, Itapaji, Egbe-Ekiti, IgbaraOdo,
33		Lagos	6°26.7´N	5°12.9´E	No	N/A	2.83	4.3	3.56	3.95	5.49	4.74	PV + G + B + C	**Oyo:**Igbeti, Shaki, Eleiyele, etc
34		Ogun	7°8.6´N	3°20.4´E	Yes	Dam & River	2.62	3.49	3.17	3.79	5.7	4.91	PV + G + B + C+ H*	**Osun:**Asejire, Ede, Oke-odo, Esa-Odo, Erinle, Ikeji-Ile.
35		Ondo	7°14.7´N	5°12.5´E	Yes	Dam	2.35	3.23	2.79	3.78	5.77	4.94	PV + G + B + C+ H*	**Ogun:**Ajura, Ijebu Igbo, etc

S/N		STATE	Latitude	Longitude	Potential for mini hydro plant		Wind Speed			Solar GHI			Mini-grid Architecture	
							Min	Max	Avg	Min	Max	Avg	Technology Configuration	Locations for Hydro Resources
36		Osun	7°47.4´N	4°32.9´E	Yes	Dam	2.41	3.35	2.87	3.73	5.74	4.89	PV + G + B + C+ H*	Ondo: Owena
37		Oyo	7°47.4´N	4°32.9´E	Yes	Dam	2.62	3.49	3.17	3.79	5.7	4.91	PV + G + B + C+ H*	

Table 7: Mini Hydro Potential, Wind Speed and Solar Irradiation (GHI) for Secondary Study Areas and Recommended Mini-Grid Architecture
**Signifies Configurations Possible Only in Selected Locations; Key: PV = Solar PV; G = Diesel Generator; B = Storage Battery; C = Converter.*

Interest Rate	LCOE @ No Subsidy	LCOE @ 25% Subsidy	LCOE @ 50% Subsidy	LCOE @ 75% subsidy
10%	$0.44	$0.39	$0.31	$0.20
15%	$0.46	$0.43	$0.37	$0.24
20%	$0.47	$0.45	$0.41	$0.27
25%	$0.48	$0.46	$0.44	$0.31
Interest Rate	Ren Fraction @ No Subsidy	Ren Fraction @ 25% Subsidy	Ren Fraction @ 50% Subsidy	Ren Fraction @ 75% Subsidy
10%	38.70%	71.20%	91.30%	94.40%
15%	1.78%	42.30%	87.60%	92.20%
20%	1.48%	1.64%	38.40%	90.00%
25%	1.23%	1.33%	1.59	87.30%

Table 8: Base-Case: Result of LCOE and Ren Fraction at Different Subsidies and Interest Rates

Interest Rate	LCOE @ No Subsidy	LCOE @ 25% Subsidy	LCOE @ 50% Subsidy	LCOE @ 75% subsidy
10%	$0.304	$0.289	$0.229	$0.154
15%	$0.340	$0.317	$0.275	$0.182
20%	$0.393	$0.343	$0.318	$0.212
25%	$0.397	$0.384	$0.328	$0.243
Interest Rate	Ren Fraction @ No Subsidy	Ren Fraction @ 25% Subsidy	Ren Fraction @ 50% Subsidy	Ren Fraction @ 75% Subsidy
10%	42.60%	42.10%	89.50%	93.40%
15%	37.40%	35.40%	85.20%	91.00%
20%	1.24%	33.00%	46.70%	89.10%
25%	0.00%	1.24%	33.1	86.30%

Table 9: Anchor and Business Case: Results of LCOE and Ren Fractions at Different Subsidy and Interest Rates

Feed-in tariff can bridge the gap between utility grid tariff and mini-grid tariff while promoting the utilization of renewable energy resources leading to significantly lower emission associated with mini-grid operations.
A combination of subsidy and mini-grid may be a good strategy toward reducing the tariff for mini-grid significantly and making it more affordable to poor people living in very remote location in Nigeria. For example, at interest rate of 15%, and subsidy of 50% of initial capital cost and replacement cost the LCOE is $0.275. With a sliding feed in tariff of $1.75 for Solar PV for the first 5 years of operation of the mini-grid during which the project should have paid back the initial investment, the feed-in tariff can be reduce by 25% for every successive 5 years. This will bring the tariff for mini-grid within the reach of the vast majority of Nigerians living in the rural areas without access to electricity.

5. Summary and Conclusions

5.1. Summary and Conclusion

This paper carried out an analysis of the NERC mini-grid regulations from an academic perspective butwith a restricted scope to the unserved area without any access to electricity from the grid and without any grid infrastructure. Real field data for load demand, demographics, occupancy patter, baseline energy utilization, current appliance endowment for each household, availability factor for each appliance were utilized. Current appliance endowment was adjusted to develop a realistic forecast of appliance endowment to avoid under or over design. The household demand was then aggregated to develop the load profile for the entire village, which was then further adjusted by a factor of 20% to account for boom time effect. This was then subjected to simulation in HOMER using the primary energy resource data obtained from NASA database and macroeconomic variables like interest rates and inflation. Two scenarios were considered: the base case scenario which utilized strictly the data obtain directly from the survey and the Anchor and Business Load (ABL) Scenario where Anchor and Business load were simulated into the load profile without altering the peak load from the base case scenario. The base case scenario was used for simulation across the 36 States of the Federation with different primary energy resources to arrive at the recommended mini-grid configuration for each state. Thereafter, detailed techno-economic analysis was carried out to check the effect of different levels of subsidy on mini-grid economics. Insight was given into the issues related to tariff parity between the tariff of the DISCOs and the mini-grid. The paper showed that even at very high subsidy for initial capital cost and replacement capital cost, tariff parity still could not be achieved between the mini-grid and utility grid. The LCOE for the ABL case was lower than the base case situation. The load factor for the ABL case was also higher than the base case situation. This paper demonstrated empirically the impact of introduction of Anchor and Business load into the mini-grid base load profile leading to lower LCOE and higher load factor. Higher subsidy yielded higher renewable energy penetration.

6. Policy Recommendations

Based on the results of the research, the following policy recommendations are offered to regulatory agencies and policy makers towards improving investment in mini grid in Nigeria and closing the energy access gaps:

- Provide support to mini-grid developers by encouraging the financial institutions to offers loans to mini-grid developers at an interest rate of about 15% which is higher than the Monetary Policy Rate but low enough to promote investment in mini-grid by giving rise to lower LCOE and tariff, while promoting higher renewable enrgy penetration at the same time.
- SMEs funding and support initiative is germane for mini-grid to allow Anchor and Business load incorporating Productive Use of Energy (PUE) into the load profile for mini-grid for rural areas. Financial support from commecial banks such as the Bank of Industries (BOI) to support small and medium scale enterprises in locations where mini-grid are sited or to be sited based on the predominant economic activities and means of livelihood of the inhabitants is essential to sustainability of mini-grids. In this, study the simulation of sachet water factory and agro processing factory for production and packaging of gari into the load profile gave lower LCOE and higher renewable penetration.
- A combination of subsidy and/or feed-in tariff for renewable energy resources should be considered as this has significant impact on affordabilit for poor folks living in remote rural areas as demonstrated through the results of our study.

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