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Techno-Economic Simulation and Analysis of Mini-grid for Underserved Urban Location in Nigeria

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Abstract:
About 40% of Nigerians lack access to electricity, mostly in the rural areas. On the other hand, reliability of supply in the urban centers connected to the national grid is also problem. This paper examines the technical and economic feasibility of mini grids in urban locations in Nigeria. Issues impeding investment in mini-grids were highlighted and necessary policies and regulatory framework for mini-grid to thrive were proffered. The renewable energy (RE) penetration potential for mini grids were highlighted in addition to the critical economic parameters, which are of interest to investors: Return on Investment (ROI), Payback and Internal Rate of Return (IRR), etc. The result of the research showed that about 30% of renewable energy penetration is achievable with mini grid adoption in addition to potential it must bridge the energy supply gap in Nigeria. The result of the study also showed that Solar PV with Battery storage were the only means of renewable energy utilization for the mini grid configuration because the wind speed for the study area was found to be too low to support utility scale electricity generation and the areas does not have mini hydro potential. Mini grid from the study also showed good potential for reduction of harmful emissions like the like CO, CO_2, SO_2, NO_x, particulate matter and unburnt hydrocarbons.

Keywords: *Mini grid, Renewable Energy, Emissions, Underserved, electricity, Solar PV*

1. Introduction

Nigerian Electricity Supply Industry (NESI) challenges include largely, poor access to electricity for remote rural communities ('unserved') as well as unreliable or epileptic and poor-quality supply for areas with grid tied electricity supply ('underserved'). These are the most primary and traditional issues. Other issues with the industry include the need to reduce the carbon footprint and harmful emissions associated with the production and distribution of electricity in Nigeria; poor liquidity in the value chain; need to diversity and expand the energy mix, ageing equipment, poor private sector participation, very high aggregate technical commercial and collection (ATC&C) losses, non-cost reflective tariff, etc. Even with the increase of electricity connection from 37.2 % in 2005 to around 57.7% in 2014, over 75 million Nigerians still do not have access to electricity supply and about 70% of them reside in remote rural and difficulty to reach areas of Nigeria (IBRD/World Bank Group, 2017).

In order to address the key issues of poor access, poor quality of supply and adverse effect on environment, the Nigerian government came up with a vision 30:30:30, which seeks to achieve 30 Giga Watts of electricity supply with 30% contribution from renewable energy resources by the year 2030. This is besides the Sustainable Development Goal (SDG) number 7 for attainment of clean and affordable energy for all. In general, the world around us is changing and increasing attention is now being given to efforts and initiatives aimed at reducing carbon dioxide emissions and other harmful emissions associated with all human activities including energy utilization. Nigeria is also a signatory to treaties and conventions towards protecting the environmental from harmful emissions and reduction of global warming including the one signed in 1994 in connection with the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil in 1992 under the auspices the United Nations Framework Convention on Climate Change (UNFCCC). As a participant at the First Conference of Parties (COP-1) to the UNFCCC which held in 1995 in Berlin, Germany and later leading to the Kyoto Protocol in 1997 in Japan; the Paris Agreement in March 2017 approved by the UNFCCC on 16th May 2017, which came into force on 15th June 2017, Nigeria has huge responsibility and obligation to reduce harmful emission capable of hurting the environment.

Without considering the environment, in general, the major solutions to energy access challenges in many developing countries include three principal initiatives: Grid extension to cover unconnected locations, Mini-grids which may be operated in both grid-connected and island mode and the Solar Home System (SHS). According to Lane, Hudson, Walley & Hamden (2018), 13.6 Million personswill be best reached through mini grid in Nigeria on the premise that 86.2 Million persons within 15 Km radius of the grid can be reached via grid extension. This assumption may be faulty or far-fetched in the sense that majority of the areas covered by the grid are currently underserved and economic activities in many of the distant locations from the grid as well as the population does not make grid extension a feasible economic venture.

Nigerian Electricity Regulations Commission (NERC) in 2016 issued a regulation for mini-grids in Nigeria providing guidelines for approval, capacity thresholds, requirements for operation of mini-grids, tariff setting guidelines and the tripartite interaction between the mini-grid developer, mini grid host communities and the electricity Distribution Company (DISCO) having exclusive jurisdiction over the mini-grid location. The NERC 2016 mini grid covers 'unserved' areas pertaining to persons living without electricity supply as well as persons living in areas with poor electricity supply 'underserved' locations. Notwithstanding this regulation, mini-grid development in Nigeria has been low and coordinated efforts are required to find out the causes and what policy directions are required to increase the contribution of mini-grids to sustainable, clean and affordable electricity supply in Nigeria.

Majority of researches into mini grids in general across the world and in Nigeria in particular have been skewed towards its application in remote rural communities. Of the few researches into mini grid in Nigeria, worthy of note is the work by Azimoh and Mbohwa (2019). Some other notable works in other parts of the world include: Bhattacharyya and Palit (2016) for South Asia, Azimoh, Klintenberg, Wallin, Karlsson, and Mbohwa, (2016) for South Africa, Bhattacharyya (2015) in Bangladesh, Lal and Raturi (2012) for Fiji Island as well as Chmiel and Bhattacharyya (2015) for Isle of Eigg, Scotland.

Majority of the foregoing works in different parts of the world and the few in Nigeriafocused on utilization of mini-grids for energy access in remote rural communities. This work focuses therefore on techno economic analysis of the mini-grid for bridging the supply gap in urban grid-connected areas using an Trans Amadi Gardens (TAG) Estate, which is a purely residential to evaluate the viability of mini-grids for electric supply system in such an Estate considering different grid-tied and island mode scenarios. The research also showed the potential for mini-grid as a business (maab) for oil and gas companies in Nigeria who may wish to begin to offset the harmful emissions associated with their operations by investing in mini-grids with high renewable energy penetration while at the same time generating revenue from such ventures. The research also examines current state of the law and legislation with respect to mini-grids and what policies may be necessary to facilitate increase private sector participation needed to achieve the required contribution of mini-grids.

2. Mini-grids Definition, Components and General Architecture

According to Dohn (2011), a mini grid can be defined as an electricity supply system that is discrete and utilizes Distributed Energy sources: conventional, renewable and storage, which are serving a group of interconnected loads. The design of a mini grid may be to operate either in connection with the grid or separate from the grid (island mode).

According to Bhattacharyya (2018), local grid systems can be classified as follows using the International Renewable Energy Agency (IRENA) categorization:

- Mini-grid: 0-100 MW.
- Micro-grids: 1-100 kW.
- Nano-grids: 0-5 kW.
- Pico-grids: 0-1 kW.

The different components of a mini grid may include: Controllers, Diesel or Gas Generator, Solar Photovoltaic (PV), wind turbine, storage, converter, boiler, hydro, electrolyzer, hydrogen tank and hydrokinetics. The components to be combined and to what degree or capacity is determined by a number of factors including the available primary energy resources (wind, hydro, solar PV, etc.); size of the load demand or mini grid; economic parameters and considerations as well as available space and other constraints.

From literature, Solar PV and battery configuration for standalonesystems are most prevalent (Biswas, 2011; Ramos & Ramos (2009); Betka & Moussi (2004); and Hoque & Kumar, 2013) in Algeria, Saudi Arabia, Bangladesh, Tanzania and Ethiopia. The configuration of the battery and wind turbines is the next most employed configuration (Mishnaevsky, Freere, Sinha, acharya, Shrestha & Manandhar, 2011 and Dangeama, 2011) in Bangladesh, Thailand and Malaysia and Bangladesh, where capacities were limited to 10 kW.

Different configurations were employed in different parts of the world for 20 kW microgrids: In Algeria and Thailand, Solar PV & Battery combination were the most employed configurations according to Sado & Mehdaoui, 2008; and Trinuruk, Sorapipatana & Chenvidhya, 2009 while Hydro and Battery were the most employed configuration in Laos.

For mini-grid systems of up to 55 kW, various architectures were employed including components like Solar PV, Wind Turbines, Diesel Generators, Batteries, etc. Solar PV and batteries were employed in most mini-grid architecture. Hybrid of Wind, Solar PV and Battery with occasional inclusion of Diesel generator seems to be the most employed architectures (Alzola et. al, 2009; Mondal & Denich, 2010, etc.) in many countries in Asia including Bangladesh, Malaysia, India and a few African Countries like Cameroun (Nfah & Ngundam, 2008) and Algeria (Maouedj, Mammeri, Draou & Benyoucef, 2014).

3. Scope of the Study and Study Area Information

Trans Amadi Gardens (TAG) chosen as the study area for this research is located in Port Harcourt, Rivers State, Nigeria and contains majorly residential buildings concentrated within an estate. The Estate is located at latitude 4°47′53.02″ N and longitude 7°2′4.36″ E, the aerial view is presented in Figure 1.0 showing the on the map position of TAG.The Estate is in one of the prime areas of the city with metered and grid connected electricity supply. Based on the surveys carried out, the Estate experiences one of the most stable electricity supply in the neighbourhood with about 18 - 22 hours of supply per day for most days where there is no general or localized fault. It is still classified as underserved as it does not have 24/7 electricity supply. The houses in the Estate is home to largely middle-class citizens who can afford basic amenities and home appliances.

The key information for TAG is presented in Table 1.0. The average number of occupants per household may change depending on the period of the year where children from boarding schools or higher institutions of learning or whether there are visitors. The electricity consumption indicated for the respecting housing types are also average values based on the result of the survey.

Figure 1: On the Map Aerial View of TAG (Area within the Blue Border)

Total Area	**228,407.83 m2**
Total Perimeter	1,901.56 m
Average Number of Persons per Household	5*
General Occupancy Type *(apart fromhouse-helps or elderly occupancy with minimal consumption observed)*	evenings, nights, few hours in the morning before going to work
Openness to mini-grid initiative	Very Supportive
Willingness and Ability to pay slightly higher tariff for mini grid supplied electricity during outage period	Yes
Total No of Housing units	296
3-Bedroom Terrace Duplexes	130
4-Bedroom Semi-Detached Duplexes	120
4-Bedroom Fully Detached Duplexes	46
Average Electricity Consumption / Household	
3-Bedroom Terrace Duplexes	750 kWh
4-Bedroom Semi-Detached Duplexes	1,000 kWh
4-Bedroom Fully Detached Duplexes	1,100 kWh

Table 1: Key Information for TAG
**This Number May Vary with Returning Children from Boarding School / Higher Institutions*

4. Methodology

This study has employed applied research methodology to carry out quantitative assessment of key parameters of an electricity supply system with a view to determining the viability or otherwise of mini-grid initiative for meeting electricity demand for an estate in an underserved urban center location through a techno-economic analysis. The techno-economic analysis involved 3 principal phases: the design of a the mini-grid to meet a particular load demand, optimization phase involving the design refinement considering the available resources, different optimal combination of components and resources, components costs and several technical considerations both for the selected components and design inputs and constraints and the final phase involving sensitivity analysis.

The Gantt Charts in Figures 2.0 and 3.0 summarize the methods and the tools for the research. The primary data were the load profile for the study area obtained through bottom-up estimation and aggregation of the hourly load profile for each household, which is a cumulation of time of use (ToU) of the appliances in each household multiplied by their rated capacity in watts. The total household hourly demand was then aggregated to obtain the hourly demand for the entire estate and then for the entire year for the estate representing 8760 hourly data. Secondary data utilized include the

Solar Global Horizontal Irradiance (GHI) and the wind speed for the estate obtained from National Aeronautics and Space Administration (NASA) Database; the inflation rate of 13.9% for December 2019 and the discount rates (interest rates) of 15%, 20% and 25% for sensitivity analysis, and geolocation data for the study area obtained froma geographic information system (GIS), Google Earth. The project Lifecyle of 25 years was considered for the simulation.

The components costs were based on components cost from original equipment manufacturers associated with standard equipment used for the modelling in HOMER. The detailed techno-economic analysis was carried out using the Hybrid Optimization Model for Electric Renewables (HOMER). Techno-economic analysis using HOMER for mini-grid simulation is a very reliable and often produces valid and acceptable result has been used by many researchers in literature including: Chmiel and Bhattacharyya (2015), Azimoh, Klintenberg, Wallin, Karlsson, and Mbohwa, (2016), Setiawan et al. (2009), Halabi et al. (2017), Bhattacharyya (2015) and Tsuanyo et al. (2015), Lal and Raturi (2012) although largely for remote rural locations.

Different power outage scenarios where mini-grid utilization will be required were considered in building the load profiles and analyzed including: 6am – 9am; 6am – 12 non; 6am – 3pm; 6am – 6pm; 6am – 9pm; 6am – 12 midnight; 6am – 3am and 6am – 6 am (24 hours outage scenario); 7 am – 7 pm and 7 pm – 7 am.

The different load profiles and scenarios for this period were utilized for the simulation and the results were analyzed and discussed. The results varied for the different periods depending on the primary energy resources available during this period and for how long the resources is available. For example, where the Solar Global Horizontal Irradiance (GHI) is available for utility grade electricity generation, this was modelled in HOMER for the different periods specified above and depending on the period under consideration, the mini grid architecture or configuration required to meet the load demand and the capacities of the components required varied from one period to another. The costs of the components varied with the capacity and usage and the quantity of useful electricity generated from the system to meet the load. The aggregation of the cost and the total quantity of electricity generated from the system were the key inputs into the calculation of Levelized Cost of Energy (LCOE).

As expected, some of the period of outage occurred in the night where Solar irradiation was not available and can not be part of the components for electricity generation and if the wind speed for the area does not support utility scale electricity generation and in the absence of hydro resources either because the resources is not available or because it is not practicable to use it for electricity generation. Also, for the day time outage where the duration is too short and does not span the period of peak irradiation intensity, the dynamics and the mini-grid architecture will vary depending on peak load for this period and the total load demand and the load factor for this period.

The different outage scenarios considered were simulated and modelled in HOMER, analyzed and the resulting parameters were discussed and interpreted.

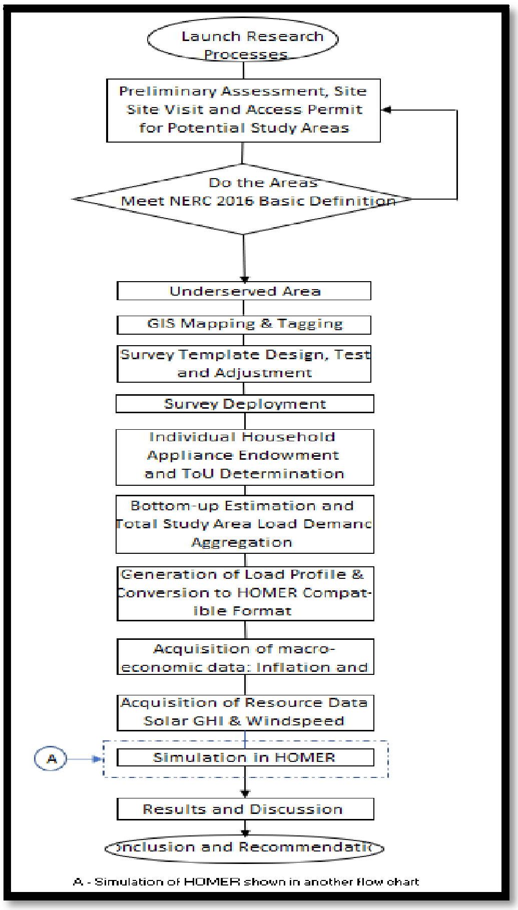

Figure 2: Overall Research Methodologies

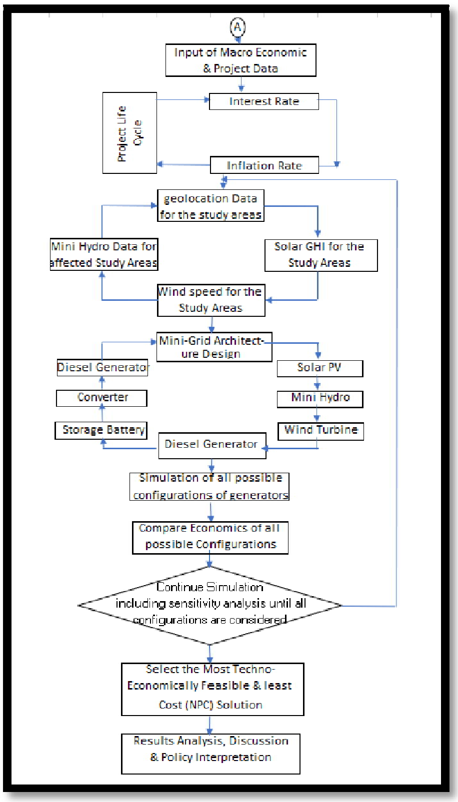

Figure 3: Simulation in HOMER

5. Results and Discussions

5.1. Load Profiles for the Different Outage Scenarios

The different load profiles for different outage period simulation where the mini gridcould be required to fill in the gap are presented below from Figure 4.0 to Figure 13.0. The key inference from the load profiles include the following:

- The lowest period of daily electricity demand occurred between 8am and 2 pm, which is consistent with occupancy pattern. Many of the occupants leave home to get to work early in the morning. Between 8 am and 2 pm, they would have gone to work and where there are aged parents or house maids in the house, the survey showed that electricity utilization by the maids were insignificant. The only exception occurred during the weekend. This research assumed same utilization for both weekends and weekdays. Although the consumption for weekends and weekdays will vary but considering the that occupants go for events, outings, religious programmes, occupancy during the weekends also gave rise to period of low consumption where occupants were not available but it was difficult to model because a predictable patter could not be established like during the weekdays.
- The peak load occurred between 6pm to 7 pm, which is also not surprising because this is the time when most members of the household would have arrived and dinner preparation is ongoing or just beginning, most appliances are engaged. Most of the rooms were occupied at this time, almost all light bulbs were on at this point as well as the air conditioners and other appliances.
- The next highest load demand to the peak load in the evening occurred between 6 am and 7 am in the morning building up from 5 am with a decline from 7am. This is the period where preparations by occupants for work were in top gear.
- While some of the outage scenarios straddles the peak period, others straddle the off-peak period.

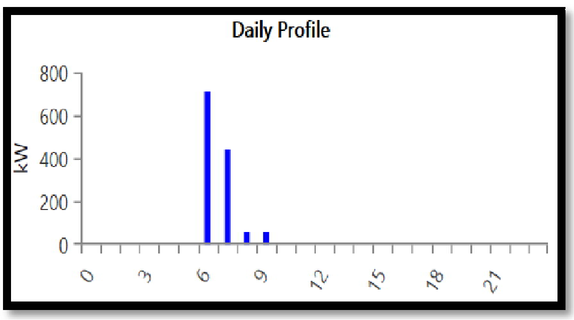

Figure 4: Daily Load Profile for Outage period 6am – 9am

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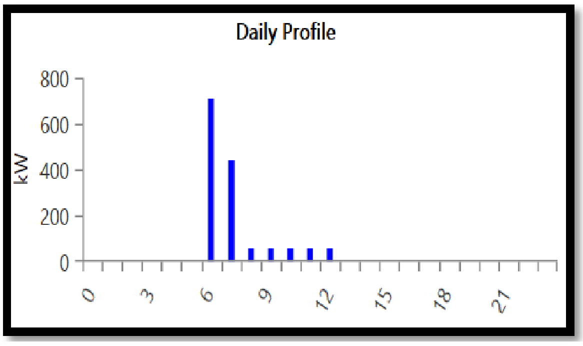

Figure 5: Daily Load Profile for Outage Period 6am – 12noon

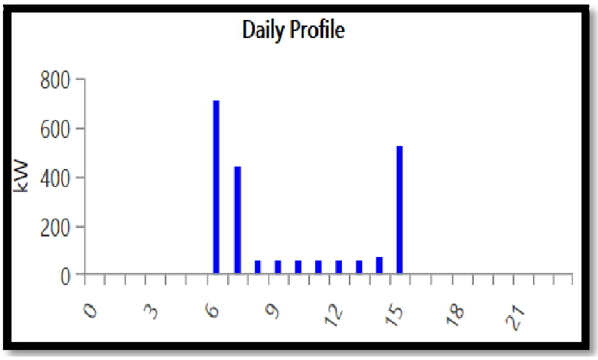

Figure 6: Daily Load Profile for Outage Period 6am – 3pm

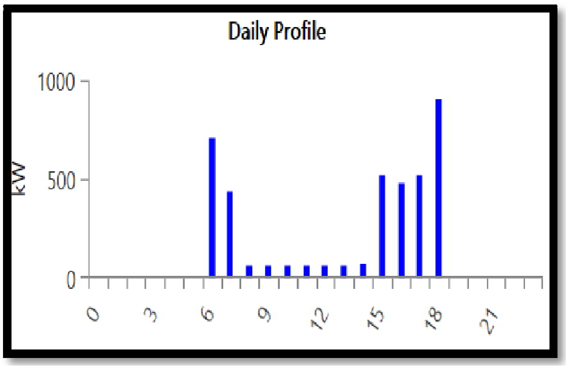

Figure 7: Daily Load Profile for Outage Period 6am – 6pm

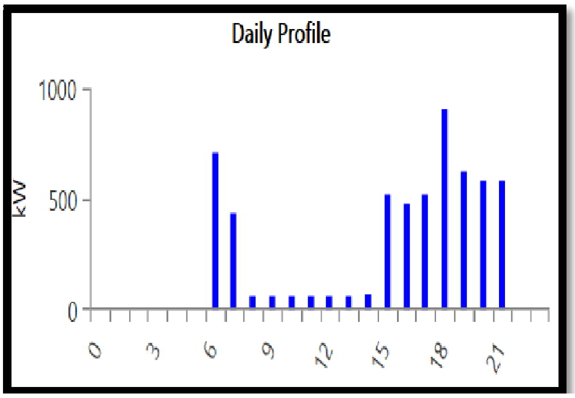

Figure 8: Daily Load Profile for Outage Period 6am – 9pm

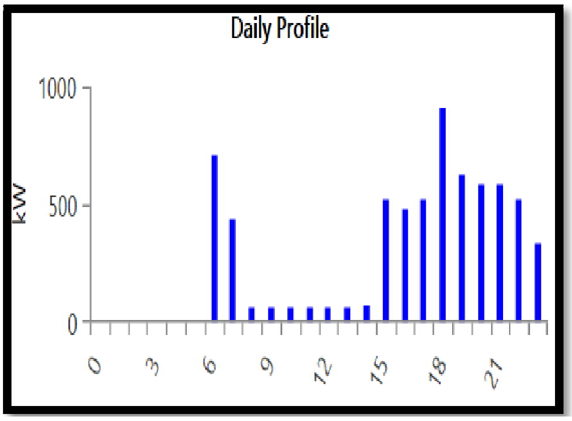

Figure 9: Daily Load Profile for Outage Period 6am – 12 Midnight

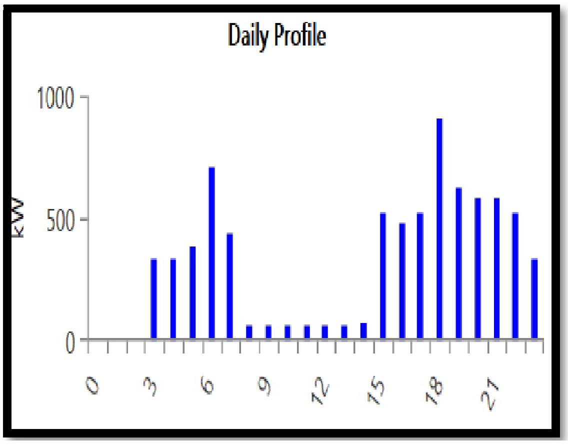

Figure 10: Daily Load Profile for Outage Period 6am – 3am

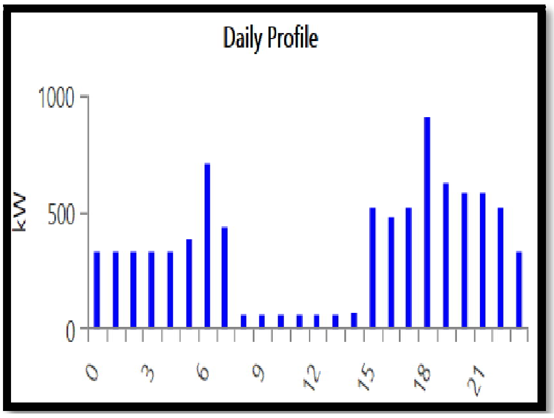

Figure 11: Daily Load Profile for – 24 Hour Outage Scenario

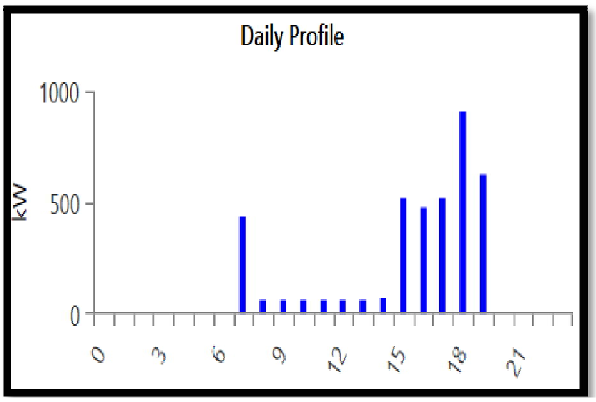

Figure 12: Daily Load Profile for Outage period 7am – 7pm

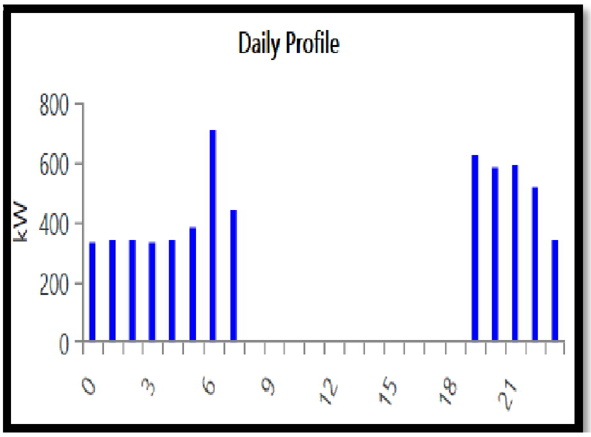

Figure 13: Daily Load Profile for Outage Period 7pm – 7am

5.2. Peak Load Information and Load Factors for the various Scenarios

The average hourly load (kW), average daily load (kWh/day), peak load (kw) and the load factor from the simulation results in HOMER are presented in Table 2.0. The inferences from this table are given below:

- Very low load factor of below 0.1 was returned for off peak period where the power outage requiring mini-grid utilization is maximum of 6 hours (i.e. 6am – 9am & 6am – 12 noon).
- Low load factor of less than 0.2 was returned for 6am – 3pm; 7am – 7 pm and 6am – 6pm.
- Higher load factors of between 0.25 and 0.34 were recorded for 6am – 9 pm; 6am – 12 midnight and 6am – 3am.
- The highest load factor occurred for the 6 am – 6 pm outage scenario where mini-grid was used exclusively to meet the entire load for the estate for the day.

Outage Period	Avg Hourly Load (kW)	Avg Daily Load (kWh/day)	Peak Load (kW)	Load Factor
6am - 9am	53	1,266	710	0.07
6am - 12 noon	60	1,443	710	0.08
6am - 3pm	88	2,102	710	0.12
6am - 6pm	167	4,015	905	0.18
6am - 9pm	242	5,816	905	0.27
6am - 12 midnight	278	6,672	905	0.31
6am - 3am	322	7,730	905	0.36
6am - 6am	364	8,741	905	0.40
7am - 7pm	164	3,934	905	0.18
7pm - 7am	245	5,874	710	0.34

Table 2: Mini-grid Load Demand Information for the Various Outage Scenarios

5.3. Solar GHI, Windspeed and Mini-grid Architecture for TAG

The Solar Global Horizontal Irradiance (GHI) is the measure of the intensity of solar radiation upon a geographical location. The solar GHI for TAG is depicted in Figure 14.0. The Annual Average solar GHI is 4.38 kWh/m2/day. The lowest Solar GHI is 3.546 kWh/m2/day with a clearness index of 0.359 while the highest is 4.923 kWh/m2/day with a clearness index of 0.516. Even the lowest Solar GHI is very good for optimal Solar PV electricity generation.

The year round Windspeed for TAG is presented in Figure 15.0. The annual average wind speed is 3.25 m/s, the lowest is 2.7 m/s, while the highest is 4.54 m/s. Even the highest windspeed is not suitable for utility scale electricity generation with wind turbine. Therefore considering the resources endowment for the study areas, the load demand, time of the demand and availability of the primary resources, the mini-grid architecture utilized in our simulation is the Diesel Generator (G) + Solar PV (PV) + Wind Turbine (T) + Storage Battery (B) + Converter (C) i.e. hybrid of G + PV + T + B + C. However, after our simulation in HOMER, the most optimal configuration to meet the load and recommended in HOMER was the hybrid of G+PV+B+C as presented in Tables 3.0 – 5.0 different interest rates (15%, 20% and 25%).

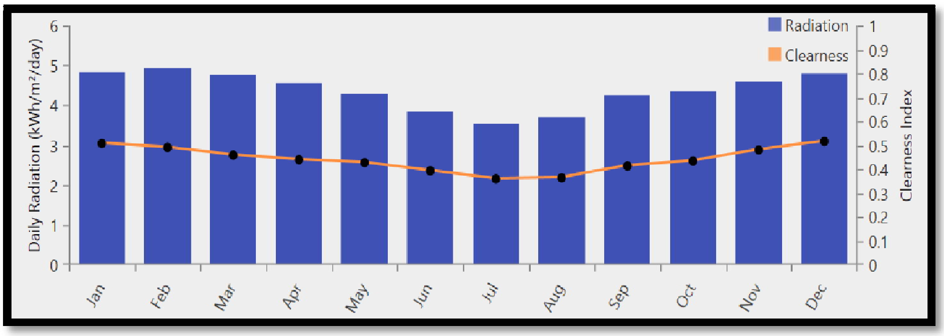

Figure 14: Solar GHI for TAG (Source: NASA Database)

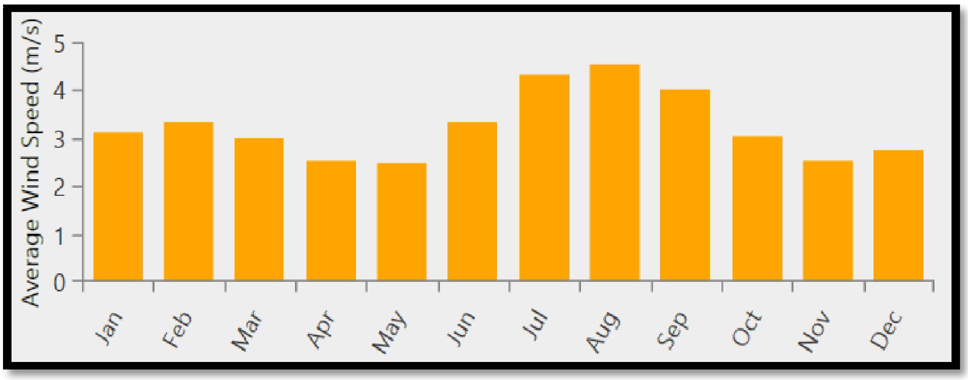

Figure 15: All-Year-Round Wind Speed for TAG (Source: NASA Database)

5.4. LCOE, Ren Frac and Mini-grid Architecture for the Various Outage Scenarios

The levelized cost of energy (LCOE) and the proxy for renewable energy penetration, the renewable fraction (Ren Frac) and the corresponding architecture at interest rates of 15%, 20% and 25% are presented in Tables 3.0 – 5.0. The following can be inferred from the results presented in this table:

- Since the study area is not 'windy' i.e. the wind resource does not support utility grade electricity generation using wind turbines and in the absence of mini or micro hydro resources, the only renewable energy resource that can be introduced into the energy mix for mini-grid operations in this location is the Solar PV.
- In general, lower interest rates gave rise to higher renewable energy penetration. The highest renewable energy penetrations were recorded across board at interest rate of 15%.
- The highest renewable energy penetration of 30. 5 % was recorded during the daytime between 7 am and 7 pm outage period which straddles the off-peak period and the beginning of peak period in the evening. This is largely explainable because the period is where you have the highest solar irradiation, which is the only primary renewable energy resources that can be practically utilized in the area.
- Therefore at 15% interest rate, significant renewable energy penetration of more than 18% could only be achieved for the 6am – 12 noon, 6am – 3 pm, 6am – 6 pm and 7am – 7 pm. This is attributable to the foregoing explanation of the limitation of the applicable renewable energy resources to solar.
- The LCOE for these periods at 15% interest rates range from $ 0.350 - $ 0.381. The LCOE in each instance for the mini grid is lower than the LCOE for the Base Case, which is the diesel generator only to meet the same load.

Outage Period	Mini grid LCOE ($)	Base Case LCOE ($)	Ren Frac	Mini Grid Architecture
6am - 9am	0.381	0.493	9.53	PV + G + B + C
6am - 12 noon	0.368	0.661	18.90	PV + G + B + C
6am - 3pm	0.350	0.647	22.60	PV + G + B + C
6am - 6pm	0.378	0.574	29.20	PV + G + B + C
6am - 9pm	0.367	0.510	10.00	PV + G + B + C
6am - 12 midnight	0.375	0.499	8.62	PV + G + B + C
6am - 3am	0.387	0.494	7.65	PV + G + B + C
6am - 6am	0.397	0.491	6.80	PV + G + B + C
7am - 7pm	0.381	0.581	30.50	PV + G + B + C
7pm - 7am	0.377	0.377	0.00	G

Table 3: LCOE, Ren Frac and Mini-grid Architecture @ 15% Interest Rates

Outage Period	Mini grid LCOE ($)	Base Case LCOE ($)	Ren Frac (%)	Mini Grid Architecture
6am - 9am	0.425	0.516	8.16	PV + G + B + C
6am - 12 noon	0.417	0.681	18.10	PV + G + B + C
6am - 3pm	0.389	0.662	20.00	PV + G + B + C
6am - 6pm	0.392	0.584	13.00	PV + G + B + C
6am - 9pm	0.385	0.518	8.91	PV + G + B + C
6am - 12 midnight	0.390	0.506	7.81	PV + G + B + C
6am - 3am	0.400	0.500	6.76	PV + G + B + C
6am - 6am	0.409	0.497	5.99	PV + G + B + C
7am - 7pm	0.395	0.591	13.40	PV + G + B + C
7pm - 7am	0.383	0.383	0.00	G

Table 4: LCOE, Ren Frac and Mini-grid Architecture @ 20% Interest Rates

Outage Period	Minigrid LCOE ($)	Base Case LCOE ($)	Ren Frac	Mini-Grid Architecture
6am - 9am	0.47	0.541	7.94	PV + G + B + C
6am - 12 noon	0.472	0.703	16.9	PV + G + B + C
6am - 3pm	0.431	0.677	18.9	PV + G + B + C
6am - 6pm	0.417	0.594	11.3	PV + G + B + C
6am - 9pm	0.403	0.525	7.91	PV + G + B + C
6am - 12 midnight	0.406	0.512	6.87	PV + G + B + C
6am - 3am	0.414	0.506	5.87	PV + G + B + C
6am - 6am	0.421	0.503	5.17	PV + G + B + C
7am - 7pm	0.421	0.601	11.6	PV + G + B + C
7pm - 7am	0.388	0.388	0	G

Table 5: LCOE, Ren Frac and Mini-grid Architecture @ 25% Interest Rates

5.5. ROI, Payback, IRR and Potential of Mini grids for Reduction of Harmful Emissions

Significant renewable energy penetration of more than 18 % could only be achieved for the 6am – 12 noon, 6am – 3 pm, 6am – 6 pm and 7am – 7 pm at 15% discount rate.

The Return on Investment (ROI), Internal Rate of Return (IRR) and Payback for these outage periods are presented in Table 4.0 and the associated harmful emission savings potential are presented in Table 5.0 including the CO2, CO, SO2, NOx, particulate matter and unburnt carbon emissions also at 15% interest rate.

Outage Period	Base Case LCOE ($)	Mini Grid LCOE ($)	ROI	IRR	Payback
6am - 12 noon	0.661	0.368	28.600	30.600	3.9 years
6am - 3pm	0.647	0.350	29.500	31.500	3.8 years
6am - 6pm	0.574	0.378	14.300	18.400	4.8 years
7am - 7pm	0.581	0.381	13.900	18.000	5 years

Table 4: ROI, IRR & Payback for Outage Period with Significant Ren Frac at 15% interest rate

Outage Period	CO_2 Kg/yr	CO kg/yr	SO_2 kg/yr	NO_x kg/yr	Particulate kg /yr	Unburnt Carbon kg / yr
6am - 12 noon	278,453	1,755	682	1,649	11	77
6am - 3pm	406,829	2,564	996	2,409	16	112
6am - 6pm	688,874	4,342	1,687	4,079	26	190
7am - 7pm	695,840	4,386	1,703	4,120	27	192

Table 5: Harmful Emissions Reduction Potential for the Mini Grid Compared to the Base Case at 15% Interest Rate

- From the emissions figures, CO_2 emission is more significantly associated with electricity generation using mini-grids than other emissions like CO, SO_2, particulate matter and unburnt carbon.
- The highest CO_2 emissions reductions occurred during the daytime i.e. period from 6 am – 6 pm and 7 am – 7 pm. This corresponds to about 30% renewable energy penetration.

6. Conclusions

Based on the Results of these research, the following conclusions can be drawn:

- Mini grids are a viable initiative for providing electricity supply both in island mode and in grid tied mode for urban centers in Nigeria. This is evident in the ROI, IRR and Payback reported in Tables 4.0.

- Mini grids hold promises for significant harmful emissions reduction associated with electricity generation from the study based on the results displayed in Table 5.0.
- High renewable energy penetration of up to 30% can ban achieved with mini-grid utilization during the day especially for the period between 6 am – 6 pm and 7 am – 7 pm. This is based on resource endowment limitation, which restricts the contribution of renewable to the mini-grid energy mix for the location to Solar PV due to poor wind speed for the area.
- The LCOE in general for the mini grid is significantly lower than the LCOE for the base case which is the utilization of diesel generator only to meet the load in addition to harmful emission to the environment associated with its usage.
- The LCOE tend to decrease with decrease in interest rates. The lowest LCOEs were recorded at the 15% interest rates.
- The most optimal mini-grid configuration was the Diesel Generator (G) + Solar PV (PV) + Storage Battery (B) + Converter (C) i.e. hybrid of G + PV + B + C. Wind resources were too low to support utility grade electricity generation using the wind turbine.
- It is expected that for the study area where micro gas turbines can be utilized where there is gas supply to the location, even lower carbon emissions can be achieved.
- In general, the period that hold promises for high renewable energy penetration also have the lowest LCOEs and they were the hours of the days with availability of solar irradiation. However, the load factors for these periods are also very low because some of these periods have high peak loads necessitating sizing the systems to meet this load while the efficient utilization of the useful electrical energy that the system is capable of producing is very low.

7. Policy Recommendation

- From the result of the simulation associated with this research, lower LCOE was achieved at low interest rates. Interest rate of 15% gave the lowest LCOE for the study area (urban center). In order to motivate and incentivize investment into mini-grid and reducing the tariffs associated with mini-grids, Nigerian Government needs to ensure that the Central Bank of Nigeria (CBN) and the commercial banks provide loans at lower interest rates to mini-grid developers.
- The LCOE for theperiods where mini grid could be utilized ranged from $ 0.350 - $ 0.381 which is far higher than the tariff from the utility grid. Therefore, a form of subsidy or feed-in-tariff for renewable energy utilization may be necessary to reduce the unit cost of electricity from the mini-grid.
- Some form of modification to the mini-grid regulations will be required to allow mini-grid developers work out a mode of operation especially during daytime with the electricity Distribution Companies (DISCOS) to permit utilization of mini-grid to meet the day time electricity demand especially from 7 am – 7 pm for underserved areas especially where there is electricity supply shortage during this period.
- Considering very low load factor (efficiency) for the day time period of mini grid utilization (which also holds promises for higher renewable energy penetration), it may be advisable for mini-grid regulation to be modified to allow mini-grids to send their excess production to the national grid thereby increasing the aggregate available electricity for distribution for the national grid.

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