Seeking workable solutions to the electrification challenge in Nigeria: Minigrid, reverse auctions and institutional adaptation

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Abstract

Solving the hydra-headed economic, technical and institutional electrification challenges in the Nigeria Power sector requires innovative insights that decentralized offgrid reverse auction with solar power plus storage offers. However, running a successful auction requires a meticulous design with in-depth understanding of the environment and data access to provide insight on what capacity to procure, locations, costs and regulatory governance.

Combining GIS, energy system optimization and market/regulation design expertise, we contribute to bridging this knowledge gap for the Nigeria Power sector. We identified the most populated consumer clusters without electricity access, made load demand projections and determined the techno-economically optimized PV plus battery storage sizes to achieve high quality power supply with some demand side management. Furthermore, we analyzed the land requirements/availability to achieve a shortlist of 233 clusters with 7.2 million people that require 3,280 MW solar PV for the proposed auction. Finally, we discussed the pathway to adapt our design to the existing market/regulatory framework.

Keywords: Nigeria Power Sector, Reverse Auction, Geographical Information System (GIS), Market Design, Energy Policy

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INTRODUCTION

Only 58% of Nigerians have access to electricity with 78% access in urban areas and 39% in rural areas (IEA and World Bank, 2017). Furthermore, an estimated 80% of those with access also use an alternative source of electricity supply, mostly diesel generators due to reliability concerns (IEA, 2017). Nigeria currently has an available grid power hovering around 4,000MW for over 190 Million people. It is estimated that the Nigeria economy loses US$ 29.3 Billion annually due to the lack of adequate power supply and is estimated to have lost US$ 470 Billion in GDP since year 2000 due to under-investment in power infrastructure (PSRIP, 2017). Providing access to electricity is frequently considered a precondition for sustainable development (Grimm et al, 2017). Growing evidence, both micro- and macroeconomic, suggests that better electricity infrastructure significantly boosts economic growth and improves a range of development outcomes (Alby et al, 2012).

Detailed geospatial modelling suggests that decentralized systems, led by solar photovoltaic in offgrid/minigrid systems, are the least-cost solution for three-quarters of the additional connections needed in Sub-Sahara Africa (IEA, 2017). In addition, renewable minigrid technologies are projected to have an especially large potential in providing universal access to electricity in Sub-Sahara Africa (Dagnachew et al, 2017). Dramatic cost declines in solar and wind technologies, and now energy storage, open the door to a reconceptualization of the roles of research and deployment of electricity production, transmission, and consumption that enable a clean energy transition (Kittner et al, 2017). Energy storage solves the temporal mismatch by storing excess PV output in a battery for later consumption (O'Shaughnessy et al, 2018).

Moreover, the long-term perspectives of the solar PV technology are very favourable based on the ongoing technological improvements and cost reductions in PV technology, batteries and electric appliances (Zubi et al, 2016). Over the last decades the growth of PV energy use was mainly driven by public incentives, but the shift to an economic driven use of solar PV electricity as one of the lowest cost electricity supplies is obvious (Jäger-Waldau, 2017). Rapidly decreasing technology costs, increasing reliability, and a growing track record of deployments has strengthened the case for the accelerated adoption of minigrid solutions (IRENA, 2016).

Nigeria has good solar resource potentials (the annual average solar radiation varies from 12.6 $MJ/m^2/day$ ($3.5kwhr/m^2/day$) in the coastal latitudes to about 25.2MJ/m2/day (7 $kwhr/m^2/day$) in the North (FGN, 2016)[5]. Despite this potential, solar PV in offgrid/minigrid applications is still in its infancy. According to a recent study for the World Bank, a cumulative capacity of 236kW solar minigrid serving about 9,100 people exist in Nigeria and the operators are charging a high price between US$0.58 and US$0.61 per kWh when they do not receive capital grants (ESMAP, 2017). As a potential solution, Arowolo (2017)[6] argued in favour of reverse auctions for solar PV plus storage for the Nigeria market and discussed how the auction run can be successfully executed. The author argued that the capacity to be contracted should be determined based on reliable power demand projections, locational information from Geographical Information System (hereinafter 'GIS') and energy system simulation tools. This is to provide reliable data on the needed procurement capacity (what to bid for) and at specified locations (where). The author posited that the availability of this information is crucial to achieve a competitive auction and effectively mitigate failure risk(s).

Models addressing electricity access typically need large volumes of reliable energy-related data and information, which in most developing countries have been limited or not available (Mentis, 2017). The use of innovative research methodologies such as the application of GIS and remote sensing technologies, spatial evaluation and interpolation of statistical and economic data will support and facilitate strategic energy decisions (Szabo et al, 2011). GIS

[5] Appendix 6 is the Solar Resource Map of Nigeria (Solargis)

[6] This paper builds on the discussion in the paper Arowolo (2017), Designing Reverse Auctions for Solar Power in Nigeria as a potential energy access solution.

are a powerful calculation and analytical tool of spatial variables (Amador and Dominguez, 2005). GIS layers can provide location specific energy-related information that has not been previously accessible to enable filling data gaps in developing countries using remote sensing techniques and allows for the assessment of spatially explicit energy demand information (Mentis, 2017).

Combining GIS, energy system optimization tools and market and regulation design expertise for research and analysis, this paper attempts to bridge the knowledge gaps and make contribution to the solar PV auction design and implementation literature for the Nigeria Power sector in five significant ways. First, we provide the consumer locations without electricity access (hereinafter 'non-electrified clusters') with their breakdown at the administrative decision-making levels (36 states plus FCT and the local governments of Nigeria). Second, we analysed the non-electrified clusters' population to determine the most populated ones that will provide the highest impact on solving electricity access problem with minigrid auctions. Third, we performed the load demand assessments and techno-economically optimized solar PV plus battery capacities for the selected clusters to achieve high quality power supply enhanced by some demand side management. Fourth, we determined the land requirements and ascertained the availability at the non-electrified clusters to come up with a shortlist of 233 non-electrified clusters that require 3,280 MW solar PV plus 7,518 lithium-ion MWhr battery storage capacities. This should be the priority locations for the first sets of solar PV plus battery storage minigrid auctions in Nigeria. Finally, we provide the policy implications and implementation guidelines to fit in our proposed design with the existing market and regulatory framework to facilitate decision-making.

We thus strengthened the argument for auctions design for the Nigeria market with the critical groundwork required for minigrid/offgrid electrification planning and the successful real-life implementation as a contribution to the achievement of SDG7 'Ensuring access to affordable, reliable, sustainable and modern energy for all by 2030' (SDG, 2015) for the Nigeria Power sector.

This paper is structured as follows: Section 2 is the literature review on geospatial electrification planning for Nigeria. Section 3 is the methodology. Section 4 is the results and discussions. Section 5 is the discussion of the regulatory limitations to overcome to successfully implement our proposed solution. Section 6 is the policy implications and section 7 is the conclusion.

2. LITERATURE REVIEW ON GEOSPATIAL ELECTRIFICATION PLANNING FOR NIGERIA

In this section, we provide a review of the literature that has attempted to use geospatial modelling for electrification planning for Nigeria.

In their study, Szabo et al 2011 applied GIS to determine whether solar PV, diesel generator or grid extension is the least cost electrification option in African countries. The authors' analysis shows where grid extension will be the least cost option based on a distance of 10km, 30km and 50 km from the low (LV), medium (MV) and high voltage (HV) lines respectively. Their result in (Szabo et al, 2011 and Szabo et al, 2013) for Nigeria as seen on the map of Africa suggests grid extension as the most economical option for a large part of Nigeria.

In a World Bank study (AFREA, 2015), the authors used the Network Planner model to determine the least-cost geospatial implementation plan for the Kano Electric Distribution Company (KEDC is one of the 11 Discos[7] in Nigeria). KEDC covers Kano, Jigawa and Katsina states. The analysis focused on the grid and offgrid roll-out to achieve universal electrification for an estimated population of 35 million people by 2030 using a weighted average household demand of 840 kWh/year. The authors concluded that grid roll-out is the least cost solution to provide power to approximately 97% of the households requiring a total cost of US$3.3 Billion

[7] Disco – Distribution Companies

for universal access in this area and to provide new or improved connections for 5.3 million projected households by 2030. In a similar World Bank study (AFREA, 2016), for the Kaduna Electric covering four states (Kaduna, Zamfara, Kebbi and Sokoto), using a weighted average household demand of 1,330 kWh/year, the authors concluded that grid roll-out is the least cost electrification for more than 99% of the households. The authors also concluded that approximately US$3.8 Billion is required to reach about 5.8 million households for an estimated 39 million people by 2030.

Mentis et al. (2017) used a spatially explicit continent-wide model (at 1km by 1km resolution) in their Open-Source Spatial Electrification Tool (OnSSET) to consider varying electricity consumption targets to derive the least cost solutions for infrastructure development and resulting generation mix for Nigeria. The authors designed ten scenarios and estimated an investment need between a low of US $11.7 Billion (20% grid, 0% minigrid and 80% standalone) and a high of US $153 Billion (78% grid,16% minigrid and 6% stand alone) to provide universal access in Nigeria. The authors' focused on a technology split between grid, minigrid and standalone solutions based on different levels of electricity access. However, the model does not provide the required macro-information to mobilize actions for initiatives such as Sustainable Energy for All or Power Africa (Mentis et al, 2017).

In a related work, Mentis et al. (2015) used GIS to analyze Nigeria on a settlement level with a grid cell size of 2.5km^2 for electrification planning using 170kWh/capita/year for rural and 350 kWh/capita/year for urban areas. In their conclusion, the authors advocated grid extension for 86% of the newly electrified population in Nigeria with 2030 as the time horizon. This will be at a cost of US$ 11.4Billion based on the assumption that there is available investment funds and human capacities.

In their paper, Ikejemba and Schuur (2016) focused on the location analysis to design a network of solar parks in Anambra State (South East Nigeria) using geographical and demographical characteristics. The authors used a square grid of 3.3km by 3.3km and assumed population is uniformly distributed around the grid points to obtain 262 suitable locations for the solar parks. The authors then made a shortlist of 71 potential locations for the installations. Furthermore, the authors assumed that households are at a distance of 30km from the nearest park and used mathematical (integer linear) programming to determine the best five solar park locations. Thereafter, they allocated the demand of each grid point to conclude that 1,157MW of generation capacity is required by 2020 in the state.

Ohiare (2015) used the network expansion planning (Network Planner) model to estimate the cost projections for three electrification technology options: (a) offgrid (solar PV with diesel generator), (b) diesel generator minigrid and (c) grid electrification. The author recommended grid extension for 98% of the currently non-electrified communities in Nigeria at an estimated total cost of US$34.5 Billion for 125 million people by 2030. However, the author mentioned the limitation of his model to include the lack of consideration for the constantly changing nature of costs brought about by economic and technological changes. Others are the assumption that all cost conditions remain unchanged throughout the planning period, the costs excluding the technical and geographical constraints of connecting the communities and the exclusion of generation cost for the grid technology (Ohiare, 2014).

Knowledge gaps in the literature

Trotter et al (2017), reviewed 306 scientific journal articles on electrification planning and related implementation analysis on Sub-Sahara Africa and identified further research need as follows. First, several reviewed articles point to the general lack and unreliability of data necessary for electrification planning. Second, no single article could be identified for 12 countries and fewer than 5 articles for 36 of the 49 countries. Third, there is no single study that has planned electrification along more than 3 out of the 5 possible value chain elements. Therefore, the authors advised that it is crucial to conduct electrification planning addressing the specific country or region where it is supposed to be implemented. Moreover, the authors concluded that it would be enlightening to understand the complete implication of a proposed alternative, from understanding the exact demand to selecting a generation technology, operation and transmission planning and the successful implementation.

Considering the research works that focus on Nigeria discussed above, AFREA (2015) and AFREA (2016) combined are limited to only seven (7) states out of the 36 states plus FCT[8] in Nigeria. Furthermore, their results could only support high level planning to provide universal grid access with the investment total cost estimate for the advocated grid extension and intensification. The authors neither discussed generation source (i.e. where the power supply for the recommended grid roll-out will come from), the currently insufficient status of power supply nor focused on the detailed design of any specific generation technology for the 97% of households in their medium-term interim off-grid solution discussed. Furthermore, their research lacks discussion on the market design and regulatory framework to make their proposal compatible with the existing system to facilitate implementation.

Furthermore, although Ohiare (2015) provided broad national coverage compared to AFREA (2015) and AFREA (2016), the author neither focused on any specific generation technology nor performed the technical scrutiny of the resource potentials at different locations to facilitate operation.

Mentis et al. (2017) and Szabo et al (2011) are at a low resolution of 1km by 1km while Mentis et al (2015) is at a grid cell size of about 2.5km^2. The papers applied frameworks developed by the authors to provide a broad and top-level overview of Nigeria. The papers lacked in-depth country discussions at the administrative levels that could facilitate informed decisions for operation and implementation.

[8] FCT means Federal Capital Territory (Abuja)

Ikejemba and Schuur's (2016) work is limited to only a state (Anambra), and is at a low resolution of 3.3km by 3.3km. In addition, the operation and implementation issues to integrate their proposal with the existing system were not discussed.

Our Present Work

We attempt to bridge the knowledge gaps identified in the literature (with a focus on Nigeria) by providing the complete implication of minigrid/offgrid electrification plan with solar PV plus battery storage technology. Our research takes an interdisciplinary approach by combining GIS (for geospatial planning at a high 100m by 100m resolution), energy system optimization tools with electricity market design and regulation expertise to achieve the following 1. Generate a robust database of the non-electrified clusters with their breakdown at the administrative levels. 2. Provide the detailed techno-economic optimizations for solar PV plus battery storage at the prioritized non-electrified clusters 3. Determine the land requirement per cluster and ascertain availability and 4. Address the implementation issues to adapt our proposed design to fit in with the existing market and regulatory framework based on in-depth understanding of the status quo in the Nigeria Power sector.

3. METHODOLOGY

Electrification modelling combining geospatial planning with energy system modelling requires a series of input data to generate a realistic scenario analysis (Cader et al, 2016). Our research approach is based on a step-by-step procedure: First, consumer clusters (such as villages, community, town or city etc.) are identified. Second, the electrification status of each consumer cluster is determined with satellite night light imagery and qualitative data from the school location dataset. Third, we provide the detailed breakdown of the non-electrified clusters at the administrative levels. Fourth, the population of the clusters are determined, and the most populated non-electrified clusters were selected for further analysis. Fifth, we applied the World Bank multi-tier framework (ESMAP, 2015) to make the demand projection at the selected non-electrified clusters. Sixth, we performed techno-economic optimization to determine the solar PV and battery sizes at the selected non-electrified clusters. Seventh, we analysed the clusters with GIS to ascertain the land availability. Finally, based on the above processes, we prioritized the most populated and feasible non-electrified clusters to run solar PV plus storage minigrid auctions in Nigeria.

3.1 Identification of consumer clusters

In this section, we will discuss the process to identify the locations of the existing and potential electricity consumers (the clusters) using population raster data, school location dataset and polling units' datasets.

Population Raster data

To identify the populated areas in Nigeria, spatial demographic dataset from (Worldpop, 2015) is used as the base source (Bertheau et al, 2016) with population density at 100 meters spatial resolution. This dataset is the most sophisticated spatially resolved (raster[9] cell pixels) dataset on population figures for Nigeria at the highest (100m by 100m) publicly available resolution. For each pixel, an estimated population number is provided. The raster pixels were analysed, and the population density threshold is set at 7 people per pixel ('ppp') i.e 700 people per km^2. This threshold indicates the location of a community, town or city.

The dataset is then reclassified into a binary dataset containing values of "1" for all areas with a population equal and above 7 'ppp' and "0" for all areas with a population below 7 'ppp'. The resulting binary raster dataset containing values of "1" are converted to a vector[10] dataset and a buffer zone with a radius of 500 meters is added around the cluster. The 500m is used based on the typical values for connecting locations within the same low voltage[11] grid.

[9] Raster is a digital aerial photographs or satellites imagery made up of matrix of pixels containing a value that represents the conditions for the area covered by the pixel.

[10] Vector use geometry (points, lines, and polygons) to represent the real world.

[11] Low voltage (LV) cable systems up to 1 kV serve to connect buildings and carry power over short distances of not more than several hundred meters (Europacable, 2014)

Finally, the populated areas are derived from the raster dataset and the consumer clusters are created. This process is illustrated below (Fig. 1).

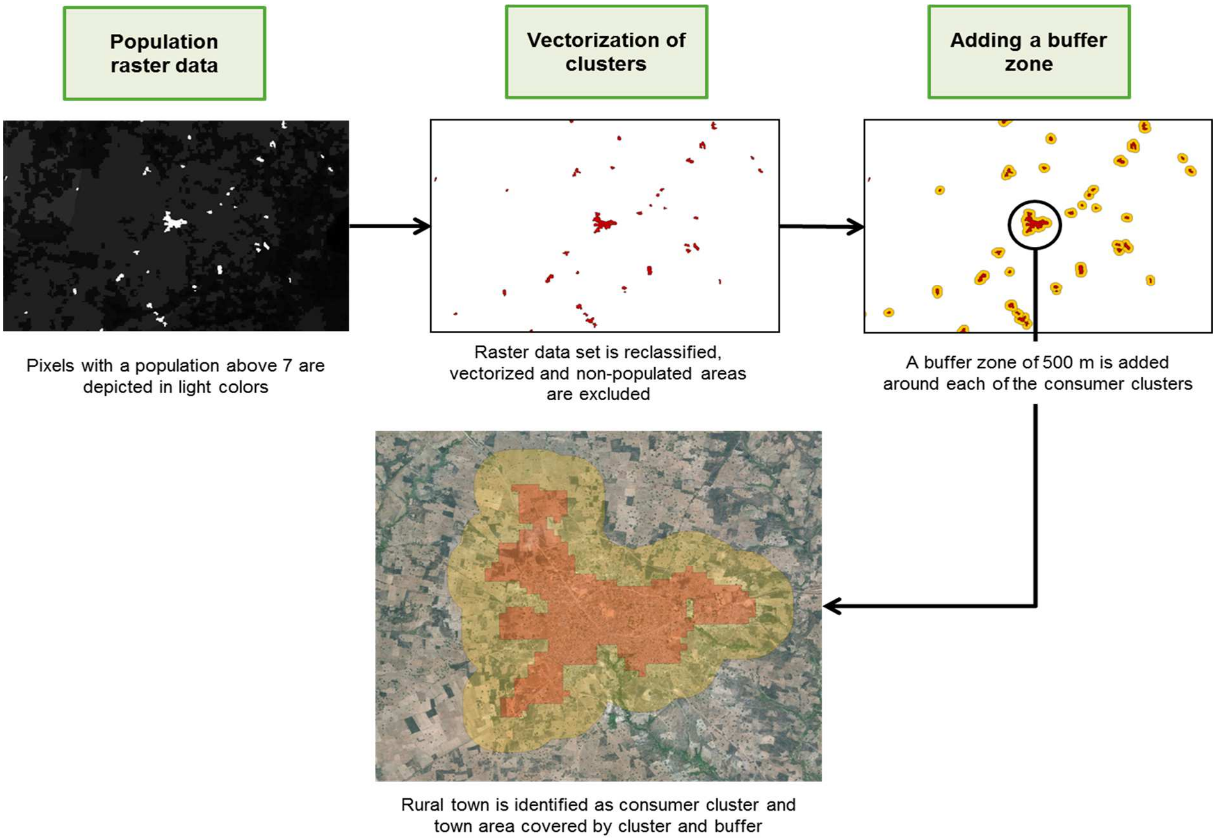

Fig 1: Identification of populated consumer clusters from raster dataset in Nigeria

Thereafter, the (Worldpop, 2015) dataset is extended with a school dataset (NMIS, 2014). The school dataset is provided by the Nigeria Millennium Development Goal (MDG) Information System. It contains information regarding the educational facilities, number of students, facilities and the administrative information of Nigeria schools. The dataset was collected by the Government and Sustainable Engineering Lab at Columbia University (NY) to facilitate local planning at the national scale of the MDG goals. Trained enumerators using android-based smartphones were used to collect locational information using GPS combined with data available through surveys as described in (Pokharel et al, 2014). This provides a rigorous, geo-referenced baseline data of 98,667 educational facilities in Nigeria. The school point dataset is used to extend the number of the consumer cluster to achieve a higher coverage of the populated areas. Similarly, a buffer zone with a radius of 500 meters is added around each of the schools.

Polling Units Dataset

To further improve accuracy, the Worldpop and school datasets were extended with the polling units' dataset of INEC - Independent National Electoral Commission (INEC, 2012) of Nigeria. INEC's data provides information about local polling units, the location of polling booths and further administrative information. This dataset covers approximately 130,000 polling locations including their latitude/longitude coordinates (geo-located) that match satellite imagery. It is comprehensive, since most settlements have at least one polling unit (AFREA, 2016). Furthermore, the INEC data is the highest resolution and most validated national data source currently available and there is often a close match between polling unit locations and human settlements, particularly larger villages which are easily identified in satellite imagery (AFREA, 2015). Similarly, a buffer zone of 500 meters is added around the polling units. The general approach is depicted below.

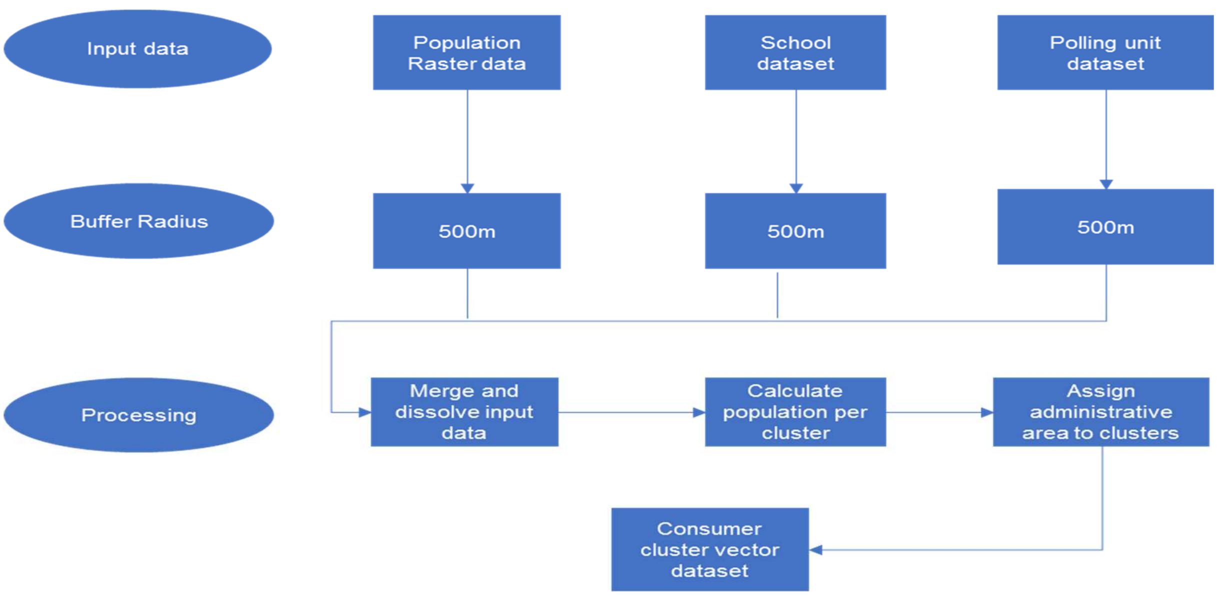

Fig. 2: Identification of consumer clusters

To create a reliable and comprehensive database useful for decision-making, we combined the three datasets to produce a robust database. With this newly created database, we calculated the population in every cluster by summing up the raster population pixel values within each cluster. Finally, administrative areas dataset for Nigeria obtained from (GADM, 2015), were assigned to each consumer cluster to further enrich the database with information at the administrative state and local government levels.

3.2 Determination of the electrification status

We determined the electrification status of the consumer clusters based on two steps:

Night light imagery (NASA, 2015): These images are satellite data which shows night light emissions over an area at a spatial resolution of 750 meters by 750 meters. These regularly visible light emissions are usually based on street lamps or other permanent lights in the villages or communities. This high amount of light activity allows the assumption that any source of electricity exist in an area (Cader et al, 2016).

Qualitative data from the school dataset (NMIS, 2014): For each school, information is provided whether the facility is grid connected or not. Each cluster was defined as electrified where a grid-connected school is located within a region with night light emissions. Consequently, all the consumer clusters with observable night light emissions and information on grid connection from the school dataset are considered electrified by grid connection. See Appendix 6 for the map of Nigeria showing the consumer clusters with nightlight emissions and electrified schools.

Administrative breakdown of the non-electrified clusters

We selected the non-electrified clusters from our model for the entire Nigeria. Thereafter, we provide their detailed breakdown at the administrative decision-making levels (36 states and FCT and at the local Government areas in Nigeria).

Determination of Minigrid Auction sites at the non-electrified clusters

Using the non-electrified clusters identified, we performed the power demand assessment by scaling the population from >=100 to >=25,000 to determine the smallest possible number of the non-electrified clusters that captures the largest population of non-electrified people for the entire country. This would be the priority locations for the solar PV plus battery storage minigrid auctions. With this process, we identified the most populated 340 non-electrified clusters.

Load Demand projection

Load demand projections were estimated using an average household size of 6 people for rural areas in Nigeria (LSMS, 2016) and the 'Tier 5' assumptions of the World Bank multi-tier framework for minimum 23 hours daily power supply (i.e. minimum of 8.2kwh/day energy consumption) covering households power supply, productive engagements and community facilities (ESMAP, 2015). This should capture currently 'suppressed' demand and the anticipated load demand growth within the first year of installation due to the migration of people to the electrified locations, industrial and commercial activities. We thus derived the load demand projections for the most populated 340 clusters.

3.3 Energy System Optimization (Solar PV plus Lithium-ion Battery Storage) Sizing

Using HOMER (Hybrid Optimization of Multiple Energy Resources) software, we determined the optimal combination of the utility scale solar PV capacity (lifetime of 25 years) and the MWh lithium-ion battery capacity (lifetime of 15 years). We used the community load profile based on the peak power demand and the yearly energy requirement (derived from the tier 5 of the multi-tier framework) at the 340 selected clusters. Please see Appendix 5 for our assumptions.

Furthermore, we performed the sensitivity analysis for five scenarios 0% (i.e. uninterrupted power supply), 5%, 10%, 15% and 20% capacity constraints. This is to ensure that for each scenario, we can analyze the different combinations of the excess energy generated and the unmet electrical load occasioned by the community load demand curve. Furthermore, the selected capacity constraints have direct techno-economic impact on the PV and battery size capacities and the Levelized Cost of Energy (hereinafter 'LCOE') calculation.

Hence, the optimized solution avoids overcapacity of solar PV panels and gives high battery autonomy. With some demand side management, it can reallocate the excess energy generated to periods with unmet load to achieve a minimum battery autonomy of 20 hours per day at the optimized LCOE. For instance, by using demand response - a reactive or preventive method to reduce, flatten or shift peak demand (Ikpe and Torriti, 2018). Demand side management solutions are crucial in energy management and planning in Africa and should be incorporated in any modelling framework (Ouedraogo, 2017). Furthermore, (Mehra et al. 2018) found that demand-side management capabilities can reduce the number of requisite solar panels and batteries due to the integration of real-time management and control.

This simulation was performed separately for each of the 340 clusters due to their different solar irradiations and ambient temperatures to decide the robust scenario per cluster. Performance assessment using location specific parameters is very valuable since PV system cannot be considered a one-size-fits-all (Okoye and Oranekwu-Okoye, 2018).

3.4 Land Requirement and Availability

A concern regarding the large-scale deployment of solar energy is its potentially significant land use (NREL, 2013). Using data for utility-scale ground-mounted fixed-tilt solar PV from the US National Renewable Energy Laboratory (NREL, 2013), we used the value of 7.6 acres (30,755.87m^2) per MW for the installations between 1MW and 20MW and 7.5acres (30351.19m^2) per MW for the installations above 20MW to compute the total land requirement for each of the 340 clusters.

Thereafter, we analyzed each of the 340 clusters with a combination of the available GIS satellite imagery from Google (2018 imagery), Bing Aerial (2018 imagery), Google Streets and Open Street Maps to ascertain the availability of the total land area required on a cluster-by-cluster basis. This analysis also helps to shortlist the number of clusters that should later be physical visited for onsite verification prior to the implementation of our proposed reverse auction. Based on the above processes, we provide the details of the best clusters for solar PV plus storage minigrid auctions in Nigeria.

4. RESULTS AND DISCUSSIONS

4.1 Non-Electrified cluster population

45,456 non-electrified clusters were identified in the entire Nigeria where an estimated 72.6 million people reside. However, about 10 million people without electricity access are out of the clusters. This population is assumed to live in small or dispersed rural settlements or have no permanent settlement locations and could not be assigned to any consumer cluster. In total, about 82.6 million people without electricity access were identified in Nigeria.

Our result is consistent in the range estimated by some renowned institutions. The World Bank estimated a total of 75 million people without electricity access in 2014 (SEAR, 2017), Renewable Energy Policy Network for the 21st century (REN21) estimated 98 million in 2014 (REN21, 2017), while the International Energy Agency (IEA) estimated 74 million without access in 2016 (IEA, 2017).

4.2. Administrative breakdown of the non-electrified clusters

Below is the map of Nigeria showing the non-electrified clusters.

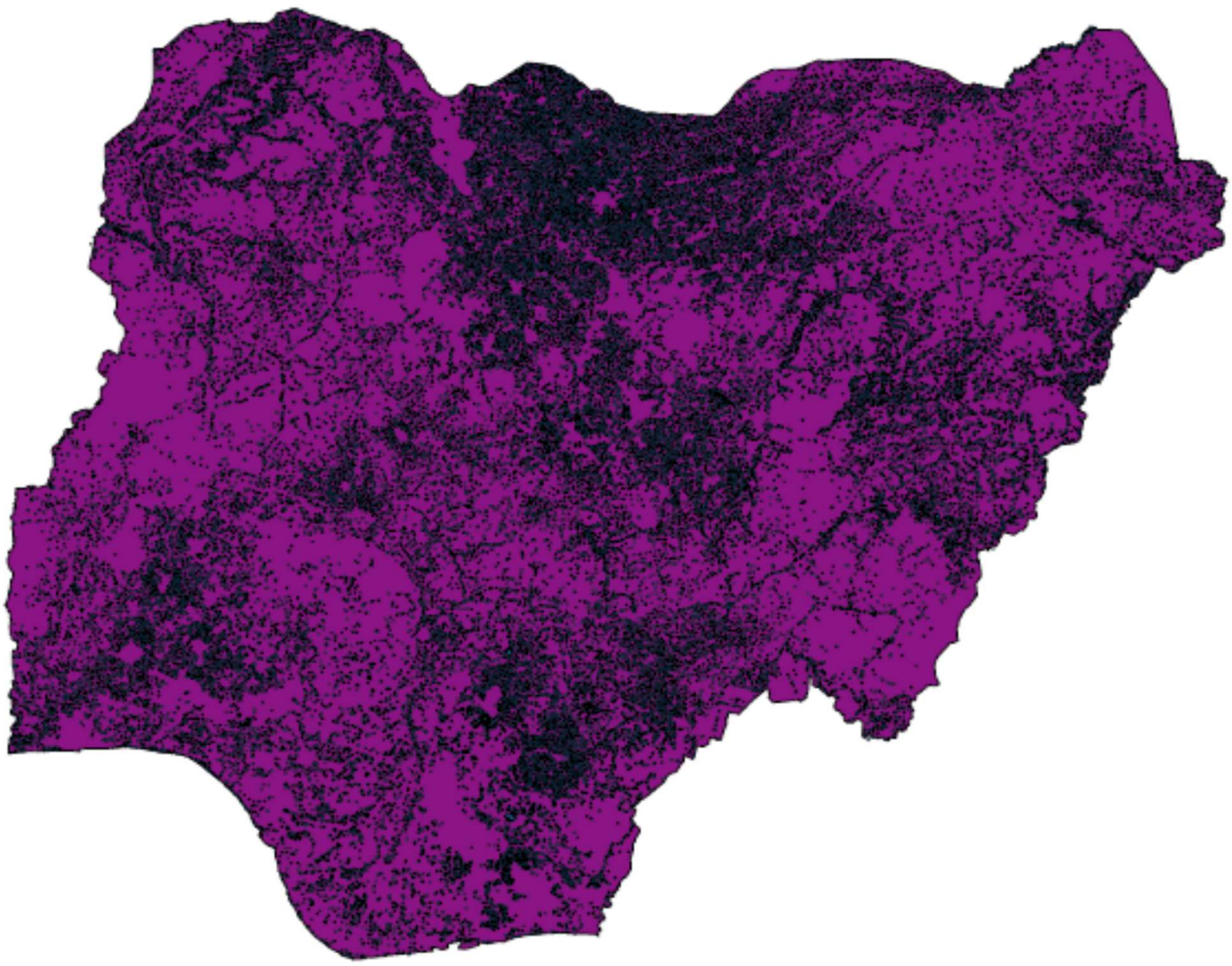

Fig 3: Map of Nigeria showing the non-electrified clusters with black dots

We also provide the information on a state by state basis (36 states plus FCT) for the local governments located in the states to provide useful information to decision makers at the individual state and local government levels (please see Appendix 2). Below is a sample result of the non-electrified clusters with the breakdown at the Local Government Area (LGA) for one of the states (Adamawa). We chose this state for illustration because it is quite representative. It has both high and low populated non-electrified clusters.

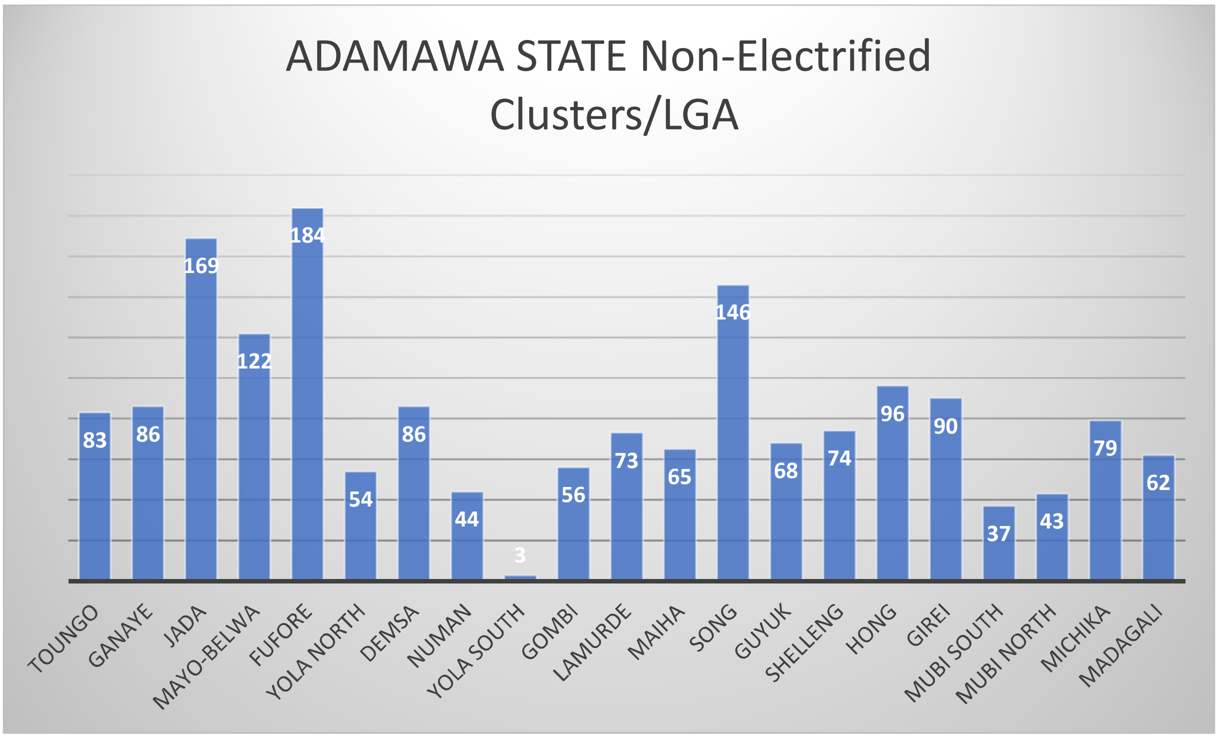

Fig 4: Non-electrified clusters at the Local Governments in Adamawa State

4.3 Determination of Minigrid Auction sites at non-electrified clusters

Below is the result of the non-electrified clusters population scaling (with a minimum of 10,000 people) in the population scale range. Please see Appendix 1 for the full table.

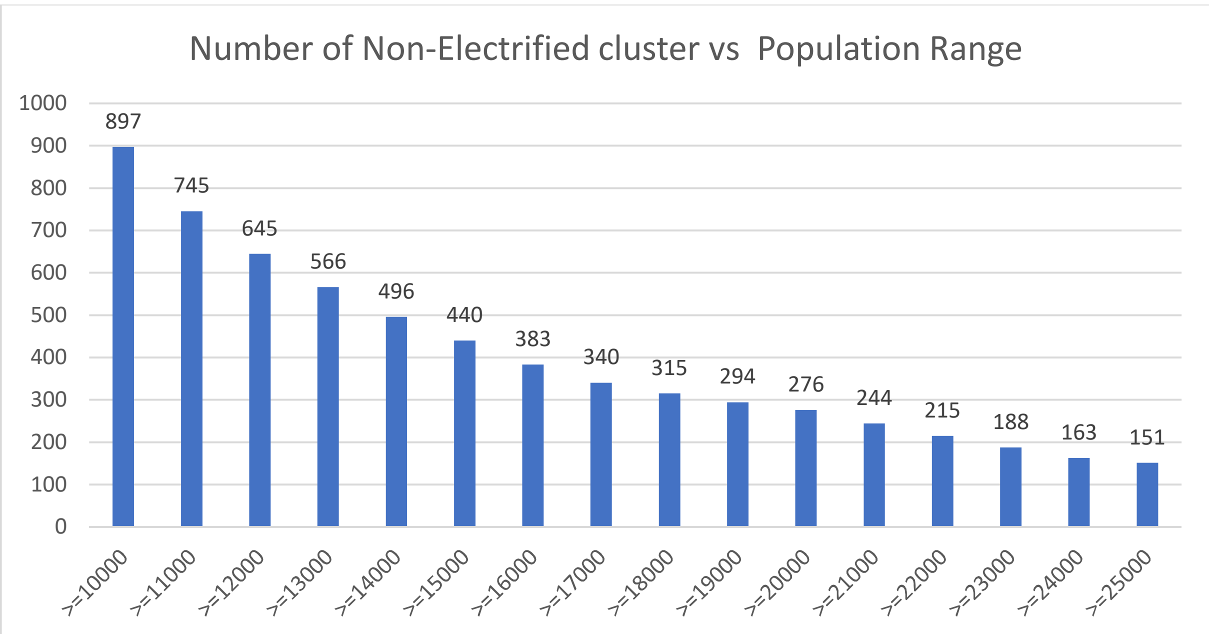

Fig 5: Number of clusters per population scale in the 10,000 to 25,000 people range

Hereinafter, we focus on the 340 most populated non-electrified clusters with more than 17,000 people per cluster with an estimated 10.1 Million people. These are the priority non-electrified clusters where the first set of auctions run can take place. Therefore, we further screen these clusters in our analysis. The locations of the 340 clusters are shown below (in black dots) on the map of Nigeria.

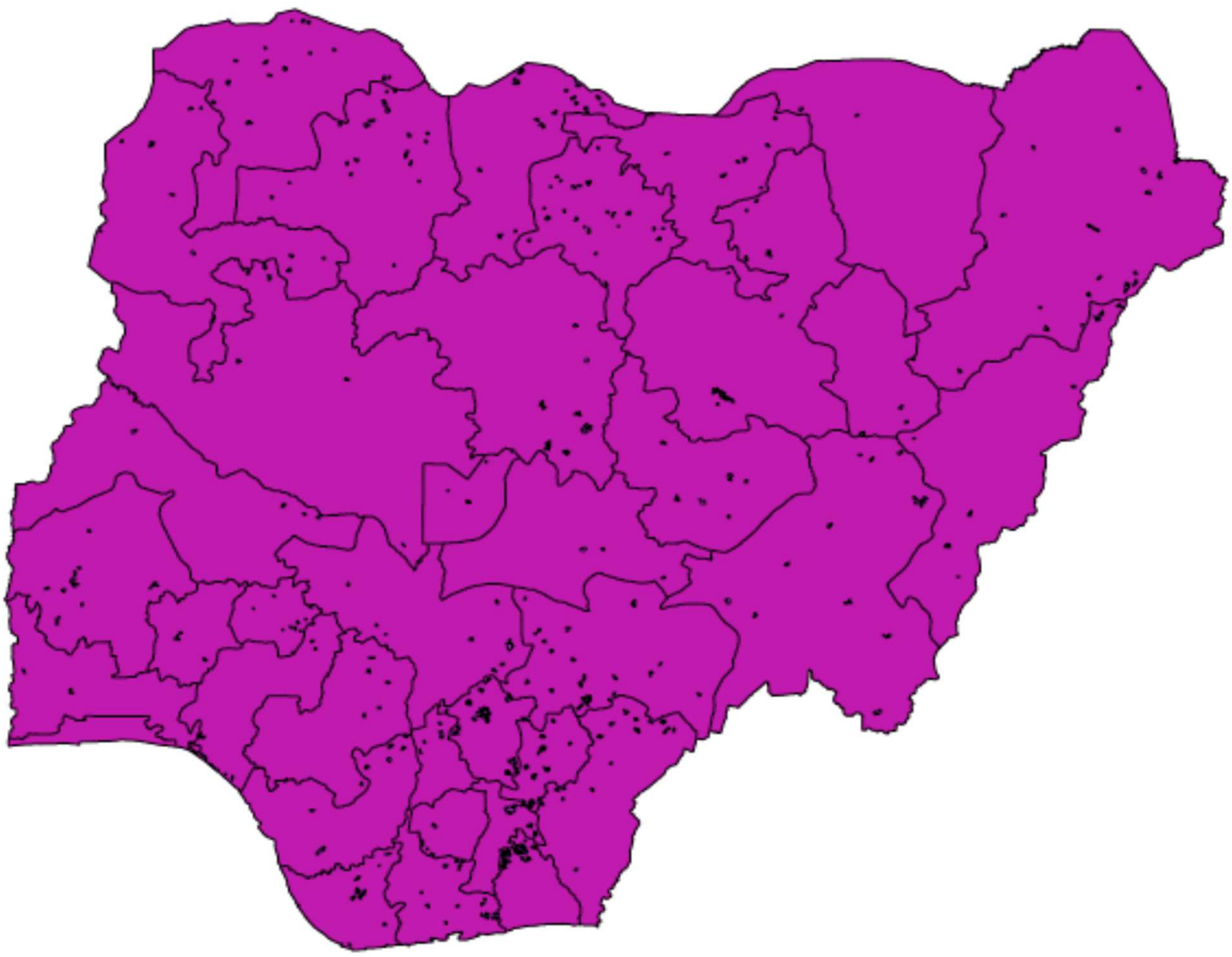

Figure 6: Map of Nigeria showing the locations of the 340 clusters

4.4 Energy System Optimization (Solar PV plus Lithium-ion Battery Storage) Sizing

We made load demand projections of the most populated 340 non-electrified clusters and simulated the PV and battery sizes in HOMER.

Below is a snapshot of some results of the sensitivity/scenario analysis for a cluster (Lamurde - we chose to illustrate this populated cluster because it is representative with an average solar irradiation of 5.64kwhr/m^2/day and yearly average air temperature of 26^{0}C).

Capacity Shortage	PV Size (MW)	Battery Size (MWh)	Autonomy (h)	Excess Energy (kWh/Year)	Unmet load (kWh/year)
0%	30.29	24	19	40,970,91	5,984
5%	8.16	27	21.4	4,160,567	384,491
10%	8.59	19	15	5,292,016	715,879
15%	7.07	18	14.2	3,195,211	1,099,923
20%	8.09	15	11.9	5,391,980	1,492,812

Table 1: Sensitivity/scenario Analysis for a cluster - Lamurde (5.64kWh/m^2/day, average 26^{0}C)

Furthermore, we performed the geospatial analysis of the clusters based on the land requirement/availability criteria. With these processes, we derived a shortlist of the optimally and carefully analyzed 233 geographical locations for the proposed minigrid solar PV plus storage reverse auction (see Appendix 3).

In total, 3,280MW solar PV capacity plus 7,518MWhr lithium-ion battery storage capacity requiring a total land area[12] of 100.55km^2 is required at these 233 non-electrified clusters. Our result shows that solar PV capacity ranges between 6.45MW and 92.55MW and lithium-ion battery sizes between 15MWh and 197MWh are required depending on the cluster. Furthermore, these 233 clusters cover approximately 7.2 Million people without electricity access that are in 187 different Local Governments in all the Nigeria states plus FCT (except Lagos).

[12] Since we anticipate the states, local governments and communities will provide the land for the projects, they should be promptly engaged to ensure buy-in of the proposed solutions and address potential socio-political obstacles.

Our result (on a finer scale for Nigeria) has enriched the literature by providing in-country micro-level data to increase understanding of the implication of using minigrid/offgrid solar PV plus battery storage for power generation and to facilitate system planning, market design and operations. Nigeria is a big and ethnically diverse country. A top-level overview or recommendation for Nigeria (at country level) e.g Szabo et al (2011), Mentis et al (2015), and Mentis et al (2017) without focusing on what specific state or what local government etc. does not seem to facilitate decision making.

Furthermore, Mentis et al (2015), Mentis et al (2017), Ohiare (2015), AFREA (2015) and AFREA (2016) analysed the investment needs for grid extension. However, funding constraints and the low wheeling capacity of the grid makes their findings challenging for stakeholders to implement. The grid's highest ever peak wheeling capacity of 5, 222 MW was achieved in December 2017 (vanguard, 2017). Moreover, grid collapse is often a recurrent problem. The national grid experienced six total system collapses in the first quarter of 2018 (NERC, 2018). We have thus provided a workable solution with solar PV offgrid/minigrid plus storage reverse auction to attract private investments and potentially solve the lack of funding and grid constraint/collapse problems.

4.5 Levelized Cost of Energy (LCOE)

The LCOE of a given technology is the ratio of the lifetime costs to the lifetime electricity generation, both of which are discounted back to a common year using a discount rate that reflects the average cost of capital (IRENA, 2018a). Appendix 5 explains how the LCOE is calculated.

The LCOE for the 233 selected non-electrified clusters (Appendix 3) range from a low of US$0.18/kWh in the North to a high of US$0.25/kWh in Southern Nigeria. It is noteworthy that, auction results in Dubai, Mexico, Peru, Chile, Abu Dhabi and Saudi Arabia obtained in 2016 and 2017 confirm that the LCOE can be reduced to US$ 0.03/kWh from 2018 onward given the right conditions (IRENA, 2018a). For instance, Dubai achieved (US$0.03/kWh), Abu Dhabi (US$0.024/kWh) and Saudi Arabia (US$ 0.023/kWh) (IRENA, 2018b). Hence, solar PV auction (without storage) have resulted in electricity prices from solar PV equal to almost a fifth of what they were in 2010, reflecting developments in the sector (IRENA, IEA and REN21, 2018).

Based on our model and analysis, we understand the added cost of the battery storage to the solar PV system. Furthermore, we have provided some critical groundwork information to facilitate the auction design for the Nigeria case. Thus, we posit that it is not impossible to expect a well-designed solar plus storage auction to produce prices in the range of US$0.09-US$0.12/kWh in Nigeria. This cost will be at the low end of the current grid tariffs and can potentially achieve high quality power supply with some demand side management.

In comparison, the current grid tariff in Nigeria (2018) range from a low of US$0.07/kWh[13] for LV residential customers in Eko Disco to a high of US$0.21/kWh for high voltage maximum demand industrial customers in Yola Disco (NERC,2015) and this power supply is only available at an average of 35.8 hours per week (LSMS, 2016). To offset these negative impacts, industrial firms in developing countries often opt for self-generation of electricity, even though it is widely considered a second-best solution (Alby et al, 2012). Most private enterprises in Nigeria are forced to resort to self-generation at a high cost to themselves and the economy at about US$0.20-0.30/kWh (World Bank, 2017). Therefore, we believe our design is techno-economically feasible for Nigeria with the right policy support frameworks addressed in the next section.

5. REGULATORY LIMITATIONS TO OVERCOME FOR BIDDERS

With the results obtained from our model and analysis, we have improved understanding of solar PV plus storage auction design for the Nigeria market. Furthermore, we have provided data on the clusters without electricity access as well as the most populated clusters that will

[13] Exchange rate conversion of ₦305.30 to 1USD (Central Official exchange rate) from the website of the Central Bank of Nigeria as at 6th March, 2018

have the largest impact on offgrid/minigrid solar PV plus battery storage reverse auction. In addition, we have ascertained the land availability and proved it is a techno-economically feasible potential solution to increase electricity access in Nigeria. In this section, we will discuss how to implement the solution from the market design and regulation viewpoint.

Nigerian Electricity Regulatory Commission Minigrids Regulation (NERC, 2016), is the current minigrid regulation guiding decision making in the Nigeria Power sector. Prospective bidders will read this regulation to make decisions on whether to participate or not in the auction run. This will have direct impact on the competitiveness of the auction. Below, we will discuss the key clauses that need to be amended or repealed in the minigrid regulation.

- NERC (2016) Section 3 defined "Independent Electricity Distribution Network" or "IEDN" as distribution network not directly connected to a transmission system operated by the system operator excluding minigrids.
  Our proposed offgrid/minigrid solution does not require connection to the transmission system. Therefore, this regulation should be amended. The successful bidders shall become Independent Electricity distribution network operators. Hence, the regulation should be expanded to make allowance for the utility scale offgrid/minigrids.
- NERC (2016) Section 4, Clause 1. This regulation shall apply to minigrids with Generation Capacity of up to 1MW. Within the regulations, the term minigrid is used for any isolated or interconnected minigrid generating between 0kW and 1MW of Generation Capacity.
  This should be amended to redefine the minigrid capacity range. The generation capacity should not be restricted to an uppermost limit of 1MW. As shown in this paper, we have identified clusters where isolated utility-scale offgrid/minigrid between 6.45MW and 92.55MW can be installed.

- NERC (2016) Section 5 Clause 2 gives the requirement for a minigrid to have a ‘generator’ in its network to be operated by a minigrid operator or a third party.

The term ‘generator’ should be clarified. If it means a fuel (such as diesel) run power supply generator, this regulation should be repealed, as there is no justification to demand a generator for minigrid installation, it should not be a requirement. We have shown in this paper that the minigrid market design is feasible and economically viable without needing a ‘generator’ in offgrid application.

- NERC (2016) Section 6, Clause 3 and 4: A minigrid developer applying for a minigrid permit shall submit to the Commission an accurate description of the proposed distribution and generation system, including geographical depiction.
  The accurate description of distribution, generation and geographical depiction of sites should not be the responsibility of the developers that have no hundred percent success guarantee in a bidding process. Otherwise, they may be deterred from participating considering the enormous transaction costs involved in gathering the information. The government should provide the information. The good news is that the effort in this research work has provided some of this critically required information, which the government can make available to prospective developers/bidders. However, this does not absolve the bidders of the responsibility to conduct their due diligence.
- Perhaps, a major regulatory limitation is related to the Distribution licensee's (i.e Discos) expansion plans and minigrid deployment. NERC (2016) Section 7, Clauses 1b, c, d, e, f and g, Section 9 and 19 needs to be amended or repealed to allow an efficient development of the minigrid. Based on the Distribution licensee's expansion plans approved by the Commission, the minigrid activities will not interfere with the expansion plans into the designated unserved area of the Discos.

The Discos expansion plans are best on paper as they lack the financial viability to bring them to fruition. Currently, the dilapidated infrastructure of the Discos do not have the capacity to fully accept the loads currently fed to them, hence load rejection is a common occurrence. In addition, publicly available financial statements of some of the Discos show they are consistently making losses since privatization (they have cumulatively made a total loss of over US$ 2 Billion between 2013 and 2016 – see Appendix 4). This is 42% more than the $1.42 Billion invested by the Discos to acquire the assets during privatization. Moreover, assessing debt financing for investment is a significant challenge for the Discos as they are unable to provide convincing cashflow projection to the lenders that shows their ability to repay loans. Although, equity funding is an investment option for the Discos to explore, it seems the Disco investors are unwilling to stake in equity considering their recent threat to the government to sell off their business at discounts. According to an investor in Jos Disco… *"You asked me whether we are willing to quit the business. Now, please listen to me and put it down clearly that we bought our distribution company cash down for $82m in 2013; we are willing to take $72m in 24 hours and leave."* [14]

Although the government (which has 40% stake) in the Discos is yet to make any investments in any of them since privatization[15]. Its recent plan to invest 72 Billion Naira (US$ 235.8 Million) as a shareholder loan in all the 11 Discos to upgrade their distribution network infrastructure is a welcome development[16]. This is in addition to the ongoing ₦702 Billion (US $ 2.3 Billion) government payment guarantee support (January 2017 - December 2018). The support is to cover the shortfall arising from the lack of cost reflective tariffs. It is paid directly through NBET[17] to the Gencos and gas companies to guarantee meeting their obligations. Besides, most Discos have received

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[14] https://punchng.com/fg-not-afraid-of-discos-threat-to-resell-firms/

[15] The total amount invested by the DISCOs to acquire 60% stake during the privatization was US$1.42 Billion. The Discos were valued at US$2.37 Billion. The Government 40% share was US$ 946 Million.

[16] https://www.thisdaylive.com/index.php/2018/07/31/fg-approves-tcn-to-manage-n72bn-planned-investment-in-power-discos/

[17] NBET is Nigeria Bulk Electricity Trading Plc – the institution coordinating transactions between the Gencos and Discos

some of their share of the ₦ 213 Billion (US$ 1.07 Billion) Nigeria Electricity Market Stabilisation Funds (NEMSF)/Power intervention loan[18].

It is noteworthy that the case of fund diversion has been alleged against some DISCO[19]. A case in point is IBEDC[20] whose board of directors were suspended for misappropriating the sum of 6 Billion Naira (US$19.6 Million from the NEMSF loan meant to improve its networks and reduce aggregate technical, commercial and collection losses and diversion of same to its shareholder company IEDMG[21]. IBEDC is yet to refund the money in line with the agreed terms with the Regulator Order of September 2017[22]. It should be enlightening to see the result of the proposed forensic audits of the DISCOs to understand the utilization of the funds received from the government post-privatization till date[23].

Furthermore, the government Ministries, Department and Agencies (MDAs) allegedly owe debts in unpaid electricity bills to the DISCOs have been verified as ₦ 27 Billion Naira (US$ 88.4 million). The government has approved that the debt should be deducted from the current debts owed by the DISCOS to NBET. NBET shall then pay the equivalent sum to the GENCOs.[24] Moreover, the government has recently approved funds to the Discos through a loan facility of ₦37bn (US$ 121Million) to assist in closing the metering gap. By October 2018, the Discos are expected to assess the fund to

[18] The Nigeria Electricity Market Stabilisation Funds (NEMSF) was a loan facility availed to the DISCO and other market players to cater for the debts owed by the privatized PHCN to the generation and gas supply companies for the energy and gas supply prior to the privatization in 2013. It also covers the market shortfall for the non-cost reflective tariffs MYTO 2.0 until January 2015 before the commencement of the transitional market.
The total deficit was 213 Billion Naira (US$1.07 Billion at the exchange rate 163 Naira/1US$) in December 2014 when it was finalized, and it was designed to fully pay off the deficit (PSRIP, 2017)

[19] http://www.nercng.org/index.php/media-library/press-releases/568-nerc-suspends-board-of-directors-of-ibadan-disco

[20] IBEDC is Ibadan Electricity Distribution Company Plc

[21] IEDMG is Integrated Energy Distribution and Marketing Group (IEDMG) Ltd

[22] http://www.nercng.org/index.php/media-library/press-releases/525-nerc-fines-ibedc-n50-million

[23] https://www.businessdayonline.com/exclusives/article/nerc-unveils-plan-tackle-liquidity-gaps-power-sector/

[24] https://www.thenigerianvoice.com/news/263279/communique-of-the-24th-monthly-meeting-of-the-honminister-o.html

contract third party investors in a bidding process to finance the procurement of meters. However, it remains to be seen if this initiative will achieve the desired result.

In a nutshell, while the government seems to be making some efforts to address the sectoral liquidity issues, refurbish some dilapidated infrastructure and to resolve the metering problems. It appears the Discos can barely survive further in business (as material uncertainty exists that cast significant doubts on their ability to continue as a going concern). This opinion was unanimously expressed by their auditors PWC, KPMG, EY etc. in their financial statement). Therefore, the Discos should focus on solving their technical and financial challenges in their current operational areas in centralized generation and give room for other private players in decentralized generation in unserved areas. This will enable the centralized and decentralized generation to effectively co-exist. As the threat of grid expansion remains a major uncertainty for the investors, any assurance in this respect can improve the investment prospects (Bhattacharyya and Palit, 2016).

On this basis, these potential investment show-stopper clauses 7, 9 and 19 and their accompanying annexes should be amended. The Commission has the power to amend or repeal, in whole or in part the provisions of the regulation as contained in Section 26 of the Regulation (NERC, 2016). Moreover, Section 71(6) of the primary legislation, Electric Power Sector Reform Act EPSRA Act. (2005) on the terms and conditions of licenses clearly shows that exclusivity was not intended for Discos licensees as follows: "*unless expressly indicated in the license, the grant of a license shall not hinder or restrict the grant of a license to another person for a like purpose and, in the absence of such an express indication, the licensee shall not claim any exclusivity, provided that the commission may allow a licensed activity to be exclusive for all or part of the period of the license for a specific purpose, for a geographical area, or for some combination of the foregoing".* Besides, there seems to be no official record till date that shows any Disco has been granted exclusivity to an unserved area. Therefore, the Regulator should amend these clauses.

Similarly, the transmission expansion plan (Fitchner, 2018) should focus on projects to refurbish the dilapidated transmission network infrastructure that causes the frequent national grid collapse (total and partial blackout) problems instead of the grid expansion projects.

6. POLICY IMPLICATIONS

6.1 Solar PV Minigrid Auction to attract investment and increase electricity access

Minigrid auction with solar PV plus storage is a workable scenario and a reasonable path forward to attract investment considering the current financial constraints bedevilling the Nigeria power sector. It is noteworthy that the three tariff increase scenarios proposed by the Government/World Bank's team in the Power Sector Recovery Program (PSRP) framework were not implemented. The only option left in the framework is to increase the tariff in July 2019 while the government supports the sector with US$7.5 Billion.

In the best-case scenario, where the government provides this fund and is able to increase tariff in July 2019, the grid can be stabilized to provide about 4,000MW of electricity by refurbishing the dilapidated infrastructure to address the frequent grid collapse problems and 5,500 MW by 2021 (PSRP, 2017).

Therefore, solar PV plus storage minigrid auction can attract investment and improve electricity access through decentralized generation competitively as shown in this paper. Our thoroughly researched shortlist of 233 non-electrified consumer clusters will provide 3,280MW with expected high socio-political acceptability as it covers all states (except Lagos) in Nigeria.

6.2. Strengthening the institutional framework

Considering the depth of regulatory concerns, strengthening the regulatory framework will improve overall market performance and restore confidence to the sector (Arowolo and Perez, 2017). Critical to an enabling environment are both the policies on the books and the effectiveness of their implementation (RISE, 2016). Existence, scope and monitoring of officially approved electrification plans, utility transparency, monitoring and creditworthiness (RISE, 2016) are good starting points to strengthen the institutional framework in Nigeria.

6.3 Capacity building for sustainability

The sustainable management of a renewable energy project after its commissioning is an important aspect. Numerous implemented projects in Sub-Sahara Africa have failed to live up to their promises because effective management method /maintenance plans were not designed (Ikejemba, 2017). To ensure sustainability[25] of off-grid solutions in the long-term, the entire supply chain should be developed and properly supported. A local ecosystem should be developed for offgrid electrification activities, including local manufacturing and assembly capacity, ancillary after-sales service system, a pool of trained technicians, and demand creating services (Bhattacharyya and Palit, 2016).

Current efforts at the National Power Training Institute of Nigeria (NAPTIN) through the six months technical skills acquisition program (NTSAP)[26] for technicians, craftsmen, artisans etc., the one-year graduate skills development programs (NGSDP)[27] for engineers and the Solar PV (SPVI[28], SPVIS[29], MGD[30] training courses) in collaboration with the AFD and IFC is commendable. Nevertheless, there is a need for an upgraded training designed for utility scale solar PV plus storage installation and design (particularly on instrumentation, automation/control and power system engineering). In addition, there is also a need for the government to fund some trainings in a sustainable way (for instance, the NGSDP is presently self-financed by the applicants). This will empower more people to meet the skills requirements of the sector and enhance sustainable solutions. Finally, to facilitate the extensive

[25] Thousands of youths and educators should be enrolled in training programs that provide hands-on experience in the design, installation, testing, operation and maintenance to acquire the skills and competencies required in the solar industry to create a sustainable pool of skilled workforce in the entire value chain. Likewise, training programs should include technical and policy training for professionals and decision makers in the sector.
[26] NTSAP means National Technical Skills Acquisition Program. It is a 6 months government sponsored program to train line maintenance technicians, distribution substation operators, cable jointing, electrical maintenance and fitters, electrical marketing and meter management technicians
[27] NGSDP is a one year Electrical/Mechanical Engineers graduate skills development program
[28] SPVI means Solar PV Installation training couse. It is a 3 week (120 hours course)
[29] SPVIS means Solar PV installer course. It is a 3 week (120 hours course)
[30] MGD means Solar PV Minigrid Design Course. It is a 4 week (160 hours course)

development of solar PV in Nigeria, trends across the country show that efforts should be improved towards education through increased awareness (Nwokocha et al, 2018).

7. CONCLUSION

This paper contributes to improving the economic, institutional and technical challenges in the Nigeria power sector through the lens of market design and regulation. We combined GIS at a high resolution with energy system optimization tools to bridge the knowledge gaps in the literature and to provide the critically needed information (at the administrative levels) to enhance decentralized offgrid reverse auctions with solar power plus storage in Nigeria.

We provide the consumer locations without electricity access with their breakdown at administrative decision-making levels (federal, 36 States plus FCT and local Governments of Nigeria). Thereafter, we analysed the most populated clusters that provide the most impact on solving electricity access problem in Nigeria with minigrid auction. Thereafter, we performed the load demand assessment and techno-economically optimized the solar PV plus battery capacities for the selected clusters to achieve high quality power supply with some demand side management.

Furthermore, we determined the land requirements and ascertained the availability of the land at the clusters to derive a final shortlist of 233 clusters covering 7.2 million people requiring 3,280 MW solar PV and 7,518MWhr battery capacities as the best locations for minigrid auctions in Nigeria. In addition, we showed it is a competitive solution with an LCOE from a low of US$0.18/kWh in the North to a high of US$0.25/kWh in Southern Nigeria and argued that it is not impossible to achieve competitive auction prices of US$0.09-US$0.12/kWh in Nigeria.

Besides, we discussed the regulatory limitations to overcome to make our proposed minigrid auction design adaptable to the Nigeria market. This centers on the need to amend or repeal specific sections and clauses in the current minigrid regulation (NERC, 2016). Finally, we provided the policy implications and guidelines to decision makers in the Nigeria power sector as follows. i. Solar PV plus storage minigrid auction can attract investment and improve electricity access through decentralized generation competitively. ii. Strengthening the institutional framework and iii. Capacity building for sustainability.

A limitation of this research is the ease of replicability. This work takes an interdisciplinary approach and has been specifically designed for Nigeria. Therefore, it cannot be replicated on the fly for another country. Furthermore, the determination of population and load profiles follows a simulation approach that may over or underestimate the results depending on the quality of input parameters. Hence, there is a need for physical site visit to the selected clusters to ascertain their current state before implementation of the auction. Thus, the attempt in this paper is by no means exhaustive.

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Appendix 1

Non-Electrified Clusters Population Scaling

Population per cluster	Total Non-electrified cluster	Total Non-electrified population covered	Percentage of non-electrified population covered
>=100	38603	72,331,296	99.54%
>=200	35443	71,870,893	98.90%
>=300	32843	71,223,400	98.01%
>=400	30344	70,349,490	96.81%
>=500	27749	69,181,032	95.20%
>=600	25308	67,842,591	93.36%
>=700	23137	66,433,973	91.42%
>=800	21214	64,992,809	89.44%
>=900	19458	63,501,751	87.39%
>=1000	17834	61,960,234	85.26%
>=2000	9178	49,700,007	68.39%
>=3000	5661	41,105,984	56.57%
>=4000	3866	34,911,454	48.04%
>=5000	2788	30,109,703	41.43%
>=6000	2118	26,447,170	36.39%
>=7000	1657	23,458,951	32.28%
>=8000	1337	21,066,789	28.99%
>=9000	1074	18,832,579	25.92%
>=10000	897	17,160,160	23.61%
>=11000	745	15,570,419	21.43%
>=12000	645	14,425,326	19.85%
>=13000	566	13,440,160	18.50%
>=14000	496	12,496,762	17.20%
>=15000	440	11,682,018	16.08%
>=16000	383	10,796,836	14.86%
>=17000	340	10,091,729	13.89%
>=18000	315	9,655,833	13.29%
>=19000	294	9,266,999	12.75%
>=20000	276	8,916,414	12.27%
>=21000	244	8,260,623	11.37%
>=22000	215	7,638,094	10.51%
>=23000	188	7,032,232	9.68%
>=24000	163	6,445,442	8.87%
>=25000	151	6,151,135	8.46%

APPENDIX 2

Breakdown of Non-Electrified clusters at the States and Local Government Levels

States	Total non-electrified cluster per state
Abia	177
Adamawa	1720
Akwa Ibom	230
Anambra	137
Bauchi	2636
Bayelsa	312
Benue	2498
Borno	2377
Cross River	789
Delta	610
Ebonyi	849
Edo	568
Ekiti	287
Enugu	360
Federal Capital Territory	310
Gombe	1056
Imo	102
Jigawa	2441
Kaduna	2998
Kano	2466
Katsina	2559
Kebbi	1559
Kogi	1256
Kwara	1053
Lagos	199
Nasarawa	1006
Niger	2618
Ogun	1073
Ondo	779
Osun	696
Oyo	1396
Plateau	1680
Rivers	333
Sokoto	1478
Taraba	1727
Yobe	1663
Zamfara	1458

State	LGA	Non-Electrified Clusters/LGA
Abia	Ukwa East	18
Abia	Ukwa West	4
Abia	Obi Nwa	17
Abia	Osisioma Ngwa	1
Abia	Isiala-Ngwa North	6
Abia	Isiala-Ngwa South	4
Abia	Ikwuano	21
Abia	Arochukwu	24
Abia	Bende	26
Abia	Umuahia South	1
Abia	Ohafia	17
Abia	Umuahia North	7
Abia	Isuikwato	16
Abia	Umu-Neochi	15
Adamawa	Toungo	83
Adamawa	Ganaye	86
Adamawa	Jada	169
Adamawa	Mayo-Belwa	122
Adamawa	Fufore	184
Adamawa	Yola North	54
Adamawa	Demsa	86
Adamawa	Numan	44
Adamawa	Yola South	3
Adamawa	Gombi	56
Adamawa	Lamurde	73
Adamawa	Maiha	65
Adamawa	Song	146
Adamawa	Guyuk	68
Adamawa	Shelleng	74
Adamawa	Hong	96
Adamawa	Girei	90
Adamawa	Mubi South	37
Adamawa	Mubi North	43
Adamawa	Michika	79
Adamawa	Madagali	62
Akwa lbom	Eastern Obolo	6
Akwa lbom	Ikot Abasi	13
Akwa lbom	Ibeno	20
Akwa lbom	Mkpat Enin	2
Akwa lbom	Onna	4
Akwa lbom	Mbo	11
Akwa lbom	Eket	2
Akwa lbom	Esit Eket	4

Akwa lbom	Urue-Offong/Oruko	2
Akwa lbom	Oruk Anam	13
Akwa lbom	Nsit Ubium	3
Akwa lbom	Okobo	12
Akwa lbom	Ukanafun	6
Akwa lbom	Udung Uko	3
Akwa lbom	Abak	1
Akwa lbom	Uruan	13
Akwa lbom	Etim Ekpo	6
Akwa lbom	Ika	5
Akwa lbom	Essien Udim	10
Akwa lbom	Ibiono Ibom	29
Akwa lbom	Obot Akara	19
Akwa lbom	Itu	2
Akwa lbom	Ikono	9
Akwa lbom	Ini	34
Anambra	Ogbaru	33
Anambra	Aguata	2
Anambra	Orumba North	10
Anambra	Anambra West	47
Anambra	Awka South	2
Anambra	Dunukofia	1
Anambra	Awka North	13
Anambra	Anambra East	14
Anambra	Ayamelum	12
Anambra	Orumba South	2
Anambra	Oyi	1
Bauchi	Bogoro	100
Bauchi	Alkaleri	144
Bauchi	Tafawa-Balewa	195
Bauchi	Dass	54
Bauchi	Bauchi	233
Bauchi	Toro	247
Bauchi	Kirfi	91
Bauchi	Ganjuwa	179
Bauchi	Ningi	170
Bauchi	Darazo	150
Bauchi	Warji	50
Bauchi	Misau	142
Bauchi	Shira	142
Bauchi	Giade	58
Bauchi	Damban	100
Bauchi	Katagum	119
Bauchi	Jama'are	42
Bauchi	Itas/Gadau	116

Bauchi	Gamawa	185
Bauchi	Zaki	119
Bayelsa	Brass	54
Bayelsa	Nembe	38
Bayelsa	Southern Ijaw	72
Bayelsa	Ogbia	14
Bayelsa	Ekeremor	68
Bayelsa	Yenegoa	13
Bayelsa	Sagbama	44
Bayelsa	Kolokuma/Opokuma	9
Benue	Ado	108
Benue	Vandeikya	145
Benue	Kwande	183
Benue	Oju	88
Benue	Ogbadibo	93
Benue	Konshisha	138
Benue	Okpokwu	61
Benue	Ushongo	118
Benue	Obi	82
Benue	Gwer East	154
Benue	Oturkpo	57
Benue	Buruku	161
Benue	Ohimini	59
Benue	Katsina-Ala	166
Benue	Gboko	183
Benue	Apa	70
Benue	Logo	99
Benue	Gwer West	70
Benue	Ukum	163
Benue	Tarka	55
Benue	Makurdi	74
Benue	Guma	122
Benue	Agatu	49
Borno	Shani	77
Borno	Bayo	61
Borno	Kwaya Kusar	38
Borno	Hawul	116
Borno	Askira/Uba	82
Borno	Biu	91
Borno	Chibok	67
Borno	Damboa	139
Borno	Gwoza	114
Borno	Konduga	136
Borno	Bama	179
Borno	Kaga	77

Borno	Jere	73
Borno	Dikwa	79
Borno	Mafa	101
Borno	Kala/Balge	92
Borno	Magumeri	109
Borno	Ngala	54
Borno	Nganzai	79
Borno	Marte	113
Borno	Monguno	85
Borno	Gubio	79
Borno	Guzamala	80
Borno	Kukawa	73
Borno	Mobbar	106
Borno	Abadam	77
Cross River	Akpabuyo	25
Cross River	Calabar South	4
Cross River	Odukpani	99
Cross River	Calabar-Municipal	1
Cross River	Akamkpa	82
Cross River	Biase	49
Cross River	Yakurr	21
Cross River	Abi	24
Cross River	Ikom	60
Cross River	Etung	24
Cross River	Obubra	54
Cross River	Boki	62
Cross River	Yala	111
Cross River	Obanliku	54
Cross River	Ogoja	67
Cross River	Obudu	29
Cross River	Bekwara	23
Delta	Burutu	58
Delta	Patani	20
Delta	Bomadi	6
Delta	Ughelli South	20
Delta	Isoko South	17
Delta	Ughelli North	30
Delta	Ndokwa East	67
Delta	Isoko North	21
Delta	Warri South West	54
Delta	Warri South	27
Delta	Ethiope East	21
Delta	Okpe	27
Delta	Ndokwa West	40
Delta	Sapele	25

Delta	Warri North	41
Delta	Ukwuani	10
Delta	Ethiope West	19
Delta	Aniocha South	42
Delta	Ika South	9
Delta	Oshimili South	8
Delta	Ika North East	14
Delta	Oshimili North	17
Delta	Aniocha North	17
Ebonyi	Afikpo South	20
Ebonyi	Afikpo North	5
Ebonyi	Ivo	9
Ebonyi	Ikwo	96
Ebonyi	Onicha	63
Ebonyi	Ohaozara	24
Ebonyi	Ezza South	57
Ebonyi	Abakaliki	96
Ebonyi	Ezza North	41
Ebonyi	Ishielu	119
Ebonyi	Izzi	160
Ebonyi	Ebonyi	78
Ebonyi	Ohaukwu	81
Edo	Orhionmwon	74
Edo	Ikpoba-Okha	38
Edo	Ovia North East	66
Edo	Ovia South West	92
Edo	Oredo	9
Edo	Uhunmwonde	81
Edo	Igueben	11
Edo	Esan South East	28
Edo	Esan West	12
Edo	Esan Central	14
Edo	Esan North East	7
Edo	Owan West	18
Edo	Owan East	21
Edo	Etsako Central	17
Edo	Etsako West	15
Edo	Etsako East	31
Edo	Akoko-Edo	34
Ekiti	Emure	38
Ekiti	Ekiti South West	25
Ekiti	Ise/Orun	19
Ekiti	Ikere	5
Ekiti	Gboyin	31
Ekiti	Ekiti West	31

Ekiti	Ado Ekiti	15
Ekiti	Efon-Alayee	17
Ekiti	Irepodun/Ifelodun	15
Ekiti	Ekiti East	12
Ekiti	Ikole	34
Ekiti	Ijero	27
Ekiti	Idosi-Osi	7
Ekiti	Oye	9
Ekiti	Ilemeji	0
Ekiti	Moba	2
Enugu	Aninri	21
Enugu	Awgu	22
Enugu	Oji-River	6
Enugu	Nkanu East	31
Enugu	Udi	15
Enugu	Ezeagu	16
Enugu	Enugu North	4
Enugu	Uzo-Uwani	37
Enugu	Enugu East	16
Enugu	Igbo-Etiti	17
Enugu	Isi-Uzo	84
Enugu	Nsukka	32
Enugu	Udenu	23
Enugu	Igbo-Eze South	17
Enugu	Igbo-Eze North	15
Enugu	Nkanu West	4
Federal Capital Territory	Kuje	47
Federal Capital Territory	Abaji	56
Federal Capital Territory	Kwali	59
Federal Capital Territory	Abuja Municipal	44
Federal Capital Territory	Gwagwalada	52
Federal Capital Territory	Bwari	52
Gombe	Shomgom	62
Gombe	Balanga	128
Gombe	Billiri	54
Gombe	Kaltungo	50
Gombe	Akko	181
Gombe	Yamaltu/Deba	139
Gombe	Kwami	76
Gombe	Dukku	177
Gombe	Funakaye	108
Gombe	Nafada	81
Imo	Ngor-Okpala	20
Imo	Ohaji/Egbema	23
Imo	Owerri West	6

Imo	Aboh-Mbaise	1
Imo	Ezinihitte	1
Imo	Oguta	11
Imo	Ihitte/Uboma	6
Imo	Oru East	2
Imo	Ehime-Mbano	6
Imo	Okigwe	19
Imo	Ideato North	4
Imo	Ideato South	1
Imo	Unuimo	2
Jigawa	Gwaram	145
Jigawa	Birni Kudu	134
Jigawa	Buji	64
Jigawa	Dutse	129
Jigawa	kiyawa	101
Jigawa	Jahun	127
Jigawa	Kafin Hausa	142
Jigawa	Ringim	134
Jigawa	Miga	49
Jigawa	Taura	76
Jigawa	Garki	147
Jigawa	Auyo	62
Jigawa	Kaugama	103
Jigawa	Gagarawa	63
Jigawa	Babura	152
Jigawa	Kiri Kasamma	65
Jigawa	Sule-Tankarkar	151
Jigawa	Malam Madori	63
Jigawa	Guri	66
Jigawa	Roni	56
Jigawa	Gumel	26
Jigawa	Kazaure	48
Jigawa	Maigatari	93
Jigawa	Biriniwa	139
Jigawa	Yankwashi	44
Jigawa	Gwiwa	62
Kaduna	Sanga	128
Kaduna	Jema'a	114
Kaduna	Kagarko	136
Kaduna	Jaba	35
Kaduna	Kachia	223
Kaduna	Kaura	29
Kaduna	Zango-Kataf	207
Kaduna	Kajuru	191
Kaduna	Chikun	236

Kaduna	Lere	195
Kaduna	Kauru	123
Kaduna	Birnin-Gwari	190
Kaduna	Igabi	302
Kaduna	Kubau	190
Kaduna	Soba	200
Kaduna	Giwa	187
Kaduna	Zaria	27
Kaduna	Ikara	110
Kaduna	Sabon-Gari	26
Kaduna	Kudan	65
Kaduna	Markafi	84
Kano	Doguwa	73
Kano	Sumaila	101
Kano	Tudun Wada	93
Kano	Kiru	116
Kano	Bebeji	67
Kano	Rano	73
Kano	Takali	76
Kano	Rogo	117
Kano	Kibiya	52
Kano	Garko	69
Kano	Albasu	48
Kano	Bunkure	73
Kano	Garum Mallam	23
Kano	Wudil	48
Kano	Karaye	72
Kano	Gaya	78
Kano	Kura	31
Kano	Madobi	50
Kano	Dawakin Kudu	38
Kano	Kabo	71
Kano	Gwarzo	58
Kano	Warawa	46
Kano	Kumbotso	7
Kano	Rimin Gado	31
Kano	Ajingi	92
Kano	Tofa	22
Kano	Shanono	128
Kano	Gezawa	34
Kano	Gabasawa	68
Kano	Ungogo	18
Kano	Bagwai	73
Kano	Dawakin Tofa	64
Kano	Minjibir	44

Kano	Bichi	80
Kano	Tsanyawa	67
Kano	Dambatta	110
Kano	Makoda	46
Kano	Kunchi	109
Katsina	Sabuwa	51
Katsina	Danja	90
Katsina	Dandume	65
Katsina	Funtua	51
Katsina	Kafur	122
Katsina	Bakori	73
Katsina	Faskari	123
Katsina	Malumfashi	65
Katsina	Kankara	136
Katsina	Musawa	93
Katsina	Dan Musa	76
Katsina	Matazuu	59
Katsina	Kankia	96
Katsina	Dutsin-Ma	65
Katsina	Sandamu	73
Katsina	Kusada	57
Katsina	Ingawa	138
Katsina	Charanchi	60
Katsina	Kurfi	71
Katsina	Bindawa	57
Katsina	Batsari	102
Katsina	Baure	102
Katsina	Rimi	63
Katsina	Batagarawa	35
Katsina	Mani	99
Katsina	Dutsi	55
Katsina	Safana	40
Katsina	Zango	60
Katsina	Jibia	82
Katsina	Daura	38
Katsina	Katsina	6
Katsina	Mashi	90
Katsina	Mai'Adua	74
Katsina	kaita	92
Kebbi	Ngaski	74
Kebbi	Yauri	34
Kebbi	Sakaba	77
Kebbi	Shanga	53
Kebbi	Bagudo	138
Kebbi	Wasagu/Danko	173

Kebbi	Koko/Besse	59
Kebbi	Zuru	52
Kebbi	Fakai	115
Kebbi	Suru	86
Kebbi	Dandi	79
Kebbi	Maiyama	42
Kebbi	Jega	39
Kebbi	Bunza	45
Kebbi	Kalgo	72
Kebbi	Arewa-Dandi	143
Kebbi	Aleiro	25
Kebbi	Gwandu	63
Kebbi	Birnin Kebbi	77
Kebbi	Argungu	58
Kebbi	Augie	55
Kogi	Ibaji	71
Kogi	Igalamela-Odolu	99
Kogi	Olamabolo	147
Kogi	Ofu	103
Kogi	Ajaokuta	24
Kogi	Ankpa	80
Kogi	Dekina	133
Kogi	Ogori/Mangongo	3
Kogi	Bassa	231
Kogi	Okene	6
Kogi	Ijumu	25
Kogi	Okehi	7
Kogi	Omala	61
Kogi	Adavi	18
Kogi	Lokoja	91
Kogi	Kabba/Bunu	31
Kogi	Kogi	78
Kogi	Yagba East	20
Kogi	Mopa-Muro	15
Kogi	Yagba West	13
Kwara	Ekiti	8
Kwara	Oke-Ero	6
Kwara	Oyun	35
Kwara	Irepodun	55
Kwara	Asa	116
Kwara	Isin	24
Kwara	Ifelodun	146
Kwara	Ilorin South	8
Kwara	Ilorin East	21
Kwara	Pategi	82

Kwara	Moro	166
Kwara	Edu	118
Kwara	Baruten	161
Kwara	Kaiama	98
Kwara	Offa	9
Lagos	Epe	97
Lagos	Ibeju/Lekki	31
Lagos	Badagry	40
Lagos	Ojo	8
Lagos	Amuwo-Odofin	3
Lagos	Ikorodu	18
Lagos	Alimosho	2
Lagos	Eti-Osa	0
Nasarawa	Doma	73
Nasarawa	Toto	104
Nasarawa	Nasarawa	145
Nasarawa	Awe	87
Nasarawa	Keana	46
Nasarawa	Lafia	132
Nasarawa	Kokona	86
Nasarawa	Nasarawa-Eggon	72
Nasarawa	Karu	125
Nasarawa	Keffi	8
Nasarawa	Wamba	56
Nasarawa	Akwanga	72
Niger	Lapai	143
Niger	Agaie	111
Niger	Mokwa	139
Niger	Katcha	139
Niger	Edati	153
Niger	Gbako	165
Niger	Lavun	94
Niger	Tafa	17
Niger	Gurara	55
Niger	Pailoro	161
Niger	Mashegu	138
Niger	Borgu	112
Niger	Bosso	103
Niger	Wushishi	75
Niger	Shiroro	200
Niger	Muya	119
Niger	Chanchaga	2
Niger	Magama	127
Niger	Rafi	127
Niger	Mariga	152

Niger	Kontagora	56
Niger	Agwara	73
Niger	Rijau	157
Ogun	Ogun waterside	73
Ogun	Ado-Odo/Ota	79
Ogun	Ipokia	64
Ogun	Ijebu East	64
Ogun	Egbado South	37
Ogun	Shagamu	27
Ogun	Ijebu ode	11
Ogun	Odogbolu	21
Ogun	Obafemi-Owode	132
Ogun	Ifo	36
Ogun	Ikenne	1
Ogun	Ijebu North East	12
Ogun	Ewekoro	52
Ogun	Ijebu North	90
Ogun	Egbado North	110
Ogun	Remo North	22
Ogun	Abeokuta North	60
Ogun	Odeda	137
Ogun	Imeko-Afon	45
Ondo	Ilaje	53
Ondo	Ese-Odo	43
Ondo	Irele	82
Ondo	Okitipupa	58
Ondo	Odigbo	75
Ondo	Idanre	81
Ondo	Ose	42
Ondo	Owo	36
Ondo	Ondo West	72
Ondo	Ondo East	36
Ondo	Akure South	26
Ondo	Ile-Oluji-Okeigbo	85
Ondo	Akure North	30
Ondo	Akoko South West	22
Ondo	Ifedore	11
Ondo	Akoko South East	4
Ondo	Akoko North East	14
Ondo	Akoko North West	9
Osun	Ife North	46
Osun	Ife South	85
Osun	Atakumosa West	72
Osun	Atakumosa East	33
Osun	Oriade	35

Osun	Ife East	1
Osun	Ife Central	9
Osun	Ilesha East	4
Osun	Aiyedade	95
Osun	Ilesha West	6
Osun	Ede South	20
Osun	Aiyedire	19
Osun	Obokun	39
Osun	Ola-oluwa	29
Osun	Ede North	7
Osun	Egbedore	20
Osun	Ejigbo	25
Osun	Osogbo	1
Osun	Boripe	11
Osun	Ifedayo	13
Osun	Orolu	9
Osun	Olorunda	8
Osun	Ila	21
Osun	Boluwaduro	9
Osun	Odo-Otin	13
Osun	Irewole	20
Osun	Isokan	22
Osun	Iwo	24
Oyo	Oluyole	61
Oyo	Ona-Ara	40
Oyo	Ido	64
Oyo	Egbeda	17
Oyo	Ibarapa East	43
Oyo	Lagelu	47
Oyo	Akinyele	75
Oyo	Ibarapa North	57
Oyo	Afijio	77
Oyo	Iseyin	58
Oyo	Oyo East	13
Oyo	Ogo Oluwa	34
Oyo	Iwajowa	62
Oyo	Surulere	107
Oyo	Oyo West	32
Oyo	Kajola	21
Oyo	Atiba	48
Oyo	Ori Ire	163
Oyo	Itesiwaju	73
Oyo	Ogbomosho South	2
Oyo	Ogbomosho North	14
Oyo	Atigbo	54

Oyo	Saki West	45
Oyo	Saki East	70
Oyo	Olorunsogo	37
Oyo	Orelope	33
Oyo	Irepo	34
Oyo	Ibarapa Central	15
Plateau	Shendam	162
Plateau	Langtang South	59
Plateau	Qua'an Pan	156
Plateau	Wase	118
Plateau	Langtang North	121
Plateau	Mikang	72
Plateau	Pankshin	150
Plateau	Bokkos	156
Plateau	Kanam	130
Plateau	Mangu	200
Plateau	Kanke	87
Plateau	Barikin Ladi	116
Plateau	Riyom	63
Plateau	Jos South	15
Plateau	Jos East	67
Plateau	Jos North	8
Rivers	Akuku Toru	51
Rivers	Bonny	29
Rivers	Andoni	3
Rivers	Degema	31
Rivers	Khana	38
Rivers	Okrika	9
Rivers	Gokana	1
Rivers	Ogu/Bolo	3
Rivers	Asari-Toru	6
Rivers	Abua/Odual	22
Rivers	Port-Harcourt	2
Rivers	Emohua	23
Rivers	Tai	0
Rivers	Oyigbo	7
Rivers	Obia/Akpor	2
Rivers	Ikwerre	14
Rivers	Etche	38
Rivers	Ahoada East	8
Rivers	Ahoada West	13
Rivers	Ogba/Egbema/Ndoni	31
Rivers	Omumma	1
Rivers	Eleme	1
Sokoto	Kebbe	71

Sokoto	Tambuwal	84
Sokoto	Tureta	62
Sokoto	Shagari	48
Sokoto	Yabo	63
Sokoto	Dange-Shuni	62
Sokoto	Rabah	79
Sokoto	Bodinga	45
Sokoto	Silame	51
Sokoto	Kware	51
Sokoto	Wamako	41
Sokoto	Isa	67
Sokoto	Sokoto North	1
Sokoto	Binji	41
Sokoto	Wurno	44
Sokoto	Goronyo	86
Sokoto	Gudu	65
Sokoto	Tangaza	103
Sokoto	Sabon Birni	126
Sokoto	Gawabawa	85
Sokoto	Gada	102
Sokoto	Illela	101
Taraba	Sardauna	169
Taraba	Takum	114
Taraba	Kurmi	87
Taraba	Ussa	118
Taraba	Gashaka	88
Taraba	Donga	116
Taraba	Bali	141
Taraba	Wukari	162
Taraba	Gassol	143
Taraba	Ibi	74
Taraba	Ardo-Kola	105
Taraba	Yorro	74
Taraba	Zing	76
Taraba	Karin-Lamido	157
Taraba	Jalingo	9
Taraba	Lau	94
Yobe	Gulani	83
Yobe	Fika	101
Yobe	Gujba	67
Yobe	Fune	157
Yobe	Nangere	91
Yobe	Damaturu	53
Yobe	Potiskum	30
Yobe	Jakusko	132

Yobe	Tarmua	64
Yobe	Geidam	107
Yobe	Bursari	121
Yobe	Bade	36
Yobe	Machina	51
Yobe	Karasuwa	99
Yobe	Yunusari	228
Yobe	Nguru	72
Yobe	Yusufari	171
Zamfara	Maru	158
Zamfara	Gusau	162
Zamfara	Anka	111
Zamfara	Bukkuyum	122
Zamfara	Tsafe	105
Zamfara	Bungudu	164
Zamfara	Gummi	79
Zamfara	Talata Mafara	109
Zamfara	Birnin Magaji	56
Zamfara	Kaura-Namoda	84
Zamfara	Bakura	52
Zamfara	Maradun	71
Zamfara	Zurmi	128
Zamfara	Shinkafi	57

Appendix 3

Results of 233 techno-economically optimized clusters (PV and Battery sizes, LCOE and Land Requirements)

	State	LGA	Ward	Population	Load MW	Load kwhr/day	PV Sizing (MW)	Battery Sizing (MWhr)	LCOE ($/kWh)	Land Requirement (acres)	Land Requirement (Sqm)
1	Abia	Arochukwu	ANIA OHOAFIA	31,447	10.5	42,977	14.55	33	0.229	110.58	447,497.91
2	Adamawa	Lamurde	SUWA	17,748	5.9	24,256	8.09	15	0.202	61.48	248,814.99
3	Adamawa	Jada	JADA II	58,605	19.5	80,094	25.03	67	0.215	187.73	759,690.22
4	Adamawa	Maiha	MAYONGULI	38,993	13.0	53,290	15.94	44	0.210	121.14	490,248.57
5	Adamawa	Madagali	DUHU/ SHUWA	20,336	6.8	27,793	7.99	20	0.199	60.72	245,739.40
6	Adamawa	Madagali	GULAK	21,649	7.2	29,587	9.71	18	0.199	73.80	298,639.50
7	Adamawa	Madagali	MADAGALI	20,425	6.8	27,915	9.01	22	0.209	68.48	277,110.39
8	Adamawa	Toungo	TOUNGO I	17,709	5.9	24,202	8.07	15	0.202	61.33	248,199.87
9	Akwa lbom	Ikot Ekpene	IKONO SOUTH	26,741	8.9	36,546	12.40	28	0.229	94.24	381,372.79
10	Akwa lbom	Ini	IKPE 11	23,464	7.8	32,067	11.91	23	0.228	90.52	366,302.41
11	Anambra	Anambra West	OROMA ETITI-ANAM	18,133	6.0	24,782	9.33	20	0.234	70.91	286,952.27
12	Anambra	Anambra West	IFITE-ANAM	25,229	8.4	34,479	13.00	29	0.240	98.80	399,826.31
13	Anambra	Ayamelum	IFITE OGWARI I	28,468	9.5	38,907	14.29	32	0.234	108.60	439,501.38
14	Anambra	Ayamelum	OMOR III	61,051	20.4	83,437	30.76	69	0.235	230.70	933,602.53
15	Bauchi	Itas/Gadau	ZUBUKI	21,095	7.0	28,830	8.77	22	0.202	66.65	269,728.98
16	Bauchi	Warji	GABANGA	20,403	6.8	27,884	8.25	22	0.204	62.70	253,735.93
17	Bauchi	Tafawa-Balewa	BUNUNU	18,208	6.1	24,884	8.17	21	0.219	62.09	251,275.46
18	Bauchi	Ganjuwa	TAUYA	23,989	8.0	32,785	9.47	27	0.208	71.97	291,258.09
19	Bauchi	Shira	FAGGO	20,798	6.9	28,423	8.52	22	0.202	64.75	262,040.01
20	Bauchi	Giade	GIADE	27,394	9.1	37,438	11.70	35	0.201	88.92	359,843.68
21	Bauchi	Itas/Gadau	ITAS	19,495	6.5	26,643	7.89	28	0.202	59.96	242,663.81

22	Bayelsa	Brass	SANGANA	19,727	6.6	26,960	11.37	20	0.233	86.41	349,694.24
23	Bayelsa	Brass	KONSHO	22,960	7.7	31,379	13.93	24	0.253	105.87	428,429.27
24	Bayelsa	Southern Ijaw	OPOROMA 1	23,026	7.7	31,469	13.97	24	0.253	106.17	429,659.50
25	Bayelsa	Yenegoa	OTUAN	24,770	8.3	33,853	14.15	27	0.256	107.54	435,195.56
26	Bayelsa	Ekeremor	OPOROMOR III	32,306	10.8	44,151	18.49	31	0.236	140.52	568,676.04
27	Bayelsa	Ekeremor	OPOROMOR I	19,819	6.6	27,086	12.43	18	0.240	94.47	382,295.46
28	Bayelsa	Sagbama	OFONI II	19,725	6.6	26,957	13.13	20	0.248	99.79	403,824.57
29	Bayelsa	Nembe	BASSAMBIRI 1	30,937	10.3	42,280	17.34	30	0.236	131.78	533,306.79
30	Benue	Gwer East	MBAIKYAAN	17,224	5.7	23,539	8.86	17	0.220	67.34	272,497.01
31	Benue	Oturkpo	UGBOJU-EHAJE	19,053	6.4	26,039	8.45	27	0.249	64.22	259,887.10
32	Benue	Oturkpo	ADOKA-ICHO	21,468	7.2	29,339	11.61	21	0.223	88.24	357,075.65
33	Benue	Apa	OIJI	21,637	7.2	29,570	10.78	22	0.221	81.93	331,548.28
34	Benue	Kwande	IKYOV	21,368	7.1	29,202	11.08	19	0.219	84.21	340,775.04
35	Benue	Obi	OBARIKE	23,460	7.8	32,062	11.23	21	0.212	85.35	345,388.42
36	Benue	Apa	IGAH-OKPAYA	20,880	7.0	28,536	9.81	22	0.220	74.56	301,715.08
37	Benue	Gwer West	IKYAGHEV	43,875	14.6	59,962	19.96	47	0.219	151.70	613,887.17
38	Benue	Guma	NZOROV	37,289	12.4	50,962	17.25	39	0.218	131.10	530,538.76
39	Borno	Askira/Uba	LASSA	18,804	6.3	25,698	8.44	20	0.209	64.14	259,579.54
40	Borno	Gubio	GUBIO TOWN I	24,778	8.3	33,863	9.52	23	0.191	72.35	292,795.88
41	Borno	Kaga	BENISHEIKH	17,556	5.9	23,993	7.75	16	0.199	58.90	238,357.99
42	Borno	Chibok	CHIBOK GARU	18,365	6.1	25,099	8.69	19	0.210	66.04	267,268.51
43	Borno	Monguno	MONGUNO	25,829	8.6	35,300	9.17	30	0.205	69.69	282,031.33
44	Borno	Gwoza	BITA / IZGE	25,716	8.6	35,146	8.80	33	0.208	66.88	270,651.66
45	Borno	Gwoza	PULKA/BOKKO	20,632	6.9	28,197	8.48	22	0.203	64.45	260,809.78
46	Borno	Kukawa	BAGA	18,984	6.3	25,945	7.37	19	0.192	56.01	226,670.76
47	Borno	Shani	GWALASHO	20,889	7.0	28,548	8.73	23	0.209	66.35	268,498.75
48	Borno	Bayo	BRIYEL	18,515	6.2	25,303	7.38	16	0.194	56.09	226,978.32
49	Borno	Gwoza	GWOZA TOWN GADAMAYO	62,415	20.8	85,301	21.32	79	0.215	159.90	647,087.32

50	Borno	Dikwa	DIKWA	20,286	6.8	27,724	8.90	21	0.204	67.64	273,727.24
51	Borno	Ngala	NGALA WARD	59,795	19.9	81,719	25.96	70	0.219	194.70	787,916.83
52	Borno	Ngala	GAMBORU \C\	69,712	23.2	95,273	32.97	67	0.209	247.28	1,000,678.65
53	Borno	Askira/Uba	ZADAWA / HAUSARI	22,056	7.4	30,143	10.36	23	0.210	78.74	318,630.81
54	Cross River	Obubra	OCHON	17,765	5.9	24,279	8.56	19	0.224	65.06	263,270.25
55	Cross River	Ikom	ABANYUM	18,486	6.2	25,264	8.29	21	0.226	63.00	254,966.16
56	Cross River	Yala	YAHE	17,853	6.0	24,398	8.64	19	0.224	65.66	265,730.72
57	Cross River	Yakurr	MKPANI/AGOI	30,098	10.0	41,133	15.61	34	0.238	118.64	480,099.13
58	Cross River	Yakurr	ASSIGA	54,304	18.1	74,215	30.22	58	0.237	229.67	929,442.39
59	Cross River	Obudu	IPONG	21,859	7.3	29,874	9.65	25	0.227	73.34	296,794.15
60	Cross River	Yala	ECHUMOFANA	33,893	11.3	46,320	16.70	31	0.217	126.92	513,623.03
61	Delta	Ika North East	OWA I	25,777	8.6	35,229	13.55	28	0.233	102.98	416,742.04
62	Delta	Aniocha North	AKWUKWU	23,858	8.0	32,606	11.46	28	0.237	87.10	352,462.27
63	Delta	Aniocha North	UKWU - NZU	21,231	7.1	29,015	10.88	20	0.224	82.69	334,623.87
64	Delta	Oshimili North	EBU	19,047	6.3	26,031	9.90	21	0.234	75.24	304,483.11
65	Delta	Bomadi	JEREMI III	27,950	9.3	38,198	15.80	27	0.236	120.08	485,942.75
66	Delta	Aniocha South	UBULU - UKU I	31,114	10.4	42,522	16.87	33	0.233	128.21	518,851.53
67	Ebonyi	Afikpo South	AMAEKE	50,773	16.9	69,390	24.17	52	0.228	181.28	733,588.20
68	Ebonyi	Afikpo South	AMATO	41,647	13.9	56,917	19.27	44	0.229	146.45	592,665.61
69	Ebonyi	Afikpo North	UWANA AFIKPO 1	20,942	7.0	28,621	10.29	21	0.228	78.20	316,477.90
70	Ebonyi	Ohaukwu	EFFIUM II	20,396	6.8	27,875	9.15	23	0.226	69.54	281,416.21
71	Edo	Etsako Central	EKPERI I	19,358	6.5	26,456	10.47	19	0.224	79.57	322,013.96
72	Edo	Etsako West	UZAIRUE NORTH WEST	21,264	7.1	29,060	11.34	21	0.223	86.18	348,771.57
73	Edo	Etsako East	OKPELLA II	25,739	8.6	35,177	12.28	27	0.221	93.33	377,682.08
74	Edo	Orhionmwon	URHONIGBE SOUTH	18,457	6.2	25,225	11.27	19	0.241	85.65	346,618.65
75	Edo	Esan Central	OPOJI	22,157	7.4	30,281	11.22	21	0.223	85.27	345,080.86

76	Edo	Esan Central	UWESSAN II	23,798	7.9	32,524	11.36	28	0.237	86.34	349,386.68
77	Ekiti	Emure	OGBONTIORO II	32,403	10.8	44,284	16.25	30	0.220	123.50	499,782.89
78	Ekiti	Emure	IMESI	18,351	6.1	25,080	9.20	17	0.220	69.92	282,954.00
79	Ekiti	Gboyin	IJAN	21,443	7.1	29,305	10.55	20	0.219	80.18	324,474.43
80	Ekiti	Gboyin	AGBADO	35,200	11.7	48,107	17.04	39	0.229	129.50	524,080.02
81	Ekiti	Gboyin	ODE I	32,281	10.8	44,117	15.98	30	0.219	121.45	491,478.80
82	Ekiti	Ekiti East	ISINBODE	17,013	5.7	23,251	9.56	17	0.229	72.66	294,026.12
83	Ekiti	Ijero	EKAMARUN WARD \B\	33,928	11.3	46,369	17.39	31	0.220	132.16	534,844.58
84	Ekiti	Ekiti East	ILASA I	20,441	6.8	27,936	12.09	20	0.232	91.88	371,838.47
85	Ekiti	Oye	ISAN / ILAFON / ILEMESO	20,943	7.0	28,622	10.82	22	0.228	82.23	332,778.51
86	Ekiti	Gboyin	ADEGBA I	20,771	6.9	28,387	11.45	21	0.229	87.02	352,154.71
87	Enugu	Uzo-Uwani	ADANI	17,621	5.9	24,082	8.82	19	0.228	67.03	271,266.77
88	Enugu	Isi-Uzo	EHAMUFU II	29,092	9.7	39,760	16.69	21	0.231	126.84	513,315.47
89	Enugu	Igbo-Etiti	OZALLA I	172,512	57.5	235,766	80.43	197	0.231	603.23	2,441,146.01
90	FCT	Gwagwalada	PAIKO	23,178	7.7	31,676	12.03	22	0.216	91.43	369,993.12
91	FCT	Kuje	KUJE	28,431	9.5	38,855	12.14	30	0.213	92.26	373,376.26
92	Gombe	Balanga	BAMBAM	22,345	7.4	30,538	10.18	19	0.202	77.37	313,094.76
93	Gombe	Kaltungo	TULA WANGE	25,452	8.5	34,784	11.56	28	0.214	87.86	355,537.86
94	Gombe	Shomgom	FILIYA	22,339	7.4	30,530	10.02	19	0.201	76.15	308,173.82
95	Imo	Ohaji/Egbema	UMUAPU	23,056	7.7	31,510	12.39	23	0.235	94.16	381,065.23
96	Imo	Ohaji/Egbema	OBITTI/MGBISHI	19,860	6.6	27,141	9.90	21	0.236	75.24	304,483.11
97	Imo	Ohaji/Egbema	ASSA/OBILE	37,632	12.5	51,430	19.18	39	0.235	145.77	589,897.59
98	Imo	Oguta	UWAORIE	26,915	9.0	36,784	13.73	28	0.236	104.35	422,278.10
99	Jigawa	Biriniwa	BIRNIWA	18,203	6.1	24,877	6.45	20	0.198	49.02	198,375.36
100	Jigawa	Kafin Hausa	BALANGU	24,409	8.1	33,359	10.95	24	0.200	83.22	336,776.78
101	Jigawa	Auyo	DAKAIYAWA	26,115	8.7	35,691	8.74	30	0.200	66.42	268,806.30

102	Jigawa	Garki	GARKI	20,268	6.8	27,699	7.21	22	0.197	54.80	221,749.82
103	Jigawa	Kiri Kasamma	TARABU	20,516	6.8	28,038	7.49	22	0.197	56.92	230,361.47
104	Kaduna	Jema'a	ASSO	24,009	8.0	32,812	10.77	21	0.204	81.85	331,240.72
105	Kaduna	Jaba	FADA	51,114	17.0	69,856	26.42	55	0.222	198.15	801,878.37
106	Kaduna	Kaura	KPAK	167,398	55.8	228,778	67.92	177	0.210	509.40	2,061,452.66
107	Kaduna	Zango-Kataf	ZONKWA	29,730	9.9	40,631	12.27	31	0.209	93.25	377,374.52
108	Kaduna	Zango-Kataf	KACHIA URBAN	20,676	6.9	28,257	9.42	18	0.205	71.59	289,720.30
109	Kaduna	Kubau	PAMBEGUA	31,958	10.7	43,675	15.70	33	0.212	119.32	482,867.16
110	Kano	Bagwai	GADANYA	17,228	5.7	23,545	7.85	15	0.203	59.66	241,433.58
111	Kano	Rano	RURUM SABON-GARI	17,387	5.8	23,762	7.55	16	0.199	57.38	232,206.82
112	Kano	Takali	TAKAI	17,044	5.7	23,293	6.98	16	0.196	53.05	214,675.97
113	Kano	Doguwa	FALGORE	23,494	7.8	32,108	10.03	20	0.197	76.23	308,481.38
114	Kano	Rogo	ROGO SABON GARI	59,738	19.9	81,641	25.79	64	0.207	193.43	782,757.13
115	Kano	Garum Mallam	KADAWA	25,858	8.6	35,339	11.24	27	0.205	85.42	345,695.98
116	Kano	Albasu	ALBASU CENTRAL	21,196	7.1	28,968	9.66	17	0.197	73.42	297,101.70
117	Kano	Garum Mallam	GARUN MALAM	20,078	6.7	27,439	8.13	19	0.197	61.79	250,045.22
118	Kano	Bunkure	KUMURYA	23,029	7.7	31,473	9.07	22	0.196	68.93	278,955.74
119	Kano	Madobi	TSAKUWA	27,521	9.2	37,612	9.40	36	0.219	71.44	289,105.18
120	Kano	Karaye	UNGUWAR HAJJI	28,984	9.7	39,612	10.73	34	0.209	81.55	330,010.49
121	Kano	Dawakin Kudu	TSAKUWA	29,340	9.8	40,098	10.11	37	0.215	76.84	310,941.85
122	Kano	Warawa	DANBAGIWA	38,017	12.7	51,956	15.25	36	0.196	115.90	469,027.02
123	Kano	Dawakin Kudu	DAWAKI	68,831	22.9	94,069	27.81	65	0.196	208.58	844,066.52
124	Kano	Kabo	KABO	25,811	8.6	35,275	11.14	27	0.205	84.66	342,620.39
125	Kano	Gwarzo	GETSO	36,548	12.2	49,948	16.13	30	0.197	122.59	496,092.18
126	Kano	Dawakin Tofa	DAWAKI EAST	40,030	13.3	54,708	16.80	41	0.200	127.68	516,698.62

127	Kano	Bagwai	BAGWAI	56,471	18.8	77,177	21.80	60	0.199	163.50	661,655.89
128	Kano	Dambatta	GALINJA	20,537	6.8	28,067	8.04	19	0.192	61.10	247,277.19
129	Katsina	Safana	RADE \B\	53,086	17.7	72,550	18.14	65	0.210	137.86	557,911.48
130	Katsina	Zango	ROGOGO/CIDA RI	22,099	7.4	30,202	8.88	23	0.195	67.49	273,112.13
131	Katsina	Daura	MAZOJI A	38,975	13.0	53,266	13.72	40	0.190	104.27	421,970.54
132	Katsina	Mai'Adua	MAI\ADUA \B\	29,324	9.8	40,076	12.94	25	0.192	98.34	397,980.96
133	Katsina	Bakori	BARDE/KWANT AKWARAN	34,530	11.5	47,191	14.99	37	0.207	113.92	461,030.49
134	Katsina	Kafur	KAFUR	27,300	9.1	37,310	10.77	31	0.209	81.85	331,240.72
135	Katsina	Dan Musa	DAN MUSA A	44,910	15.0	61,377	19.62	46	0.201	149.11	603,430.17
136	Katsina	Ingawa	DORO	20,409	6.8	27,892	7.87	19	0.192	59.81	242,048.70
137	Kebbi	Wasagu/Danko	RIBAH/MACHIK A	26,468	8.8	36,172	11.27	29	0.209	85.65	346,618.65
138	Kebbi	Koko/Besse	KOKO MAGAJI	26,520	8.8	36,244	11.15	30	0.212	84.74	342,927.95
139	Kebbi	Maiyama	SARANDOSA/G UBBA	21,789	7.3	29,779	10.24	23	0.211	77.82	314,940.11
140	Kebbi	Arewa-Dandi	KANGIWA	23,134	7.7	31,616	10.54	23	0.202	80.10	324,166.87
141	Kebbi	Augie	AUGIE SOUTH	24,688	8.2	33,740	11.90	19	0.193	90.44	365,994.85
142	Kebbi	Bagudo	LOLO/GIRIS	17,415	5.8	23,800	7.19	17	0.201	54.64	221,134.71
143	Kebbi	Sakaba	TUDUN KUKA	27,265	9.1	37,262	10.87	32	0.213	82.61	334,316.31
144	Kebbi	Birnin Kebbi	MAURIDA /KARYO/UNG. MIJIN-NAN	19,283	6.4	26,353	7.48	18	0.192	56.85	230,053.91
145	Kebbi	Wasagu/Danko	WASAGU	21,163	7.1	28,923	9.20	23	0.209	69.92	282,954.00
146	Kogi	Olamabolo	OGUGU III	23,403	7.8	31,984	12.49	23	0.223	94.92	384,140.82
147	Kogi	Ankpa	ANKPA TOWNSHIP	131,669	43.9	179,947	56.23	150	0.223	421.73	1,706,647.27
148	Kogi	Dekina	ADUMU EGUME	40,166	13.4	54,894	17.89	44	0.221	135.96	550,222.51
149	Kogi	Adavi	EBIYA SOUTH	25,785	8.6	35,240	11.01	30	0.221	83.68	338,622.13

150	Kogi	Ijumu	AIYEGUNLE	22,684	7.6	31,001	11.37	21	0.220	86.41	349,694.24
151	Kogi	Olamabolo	OLAMABORO III	18,128	6.0	24,774	8.61	19	0.220	65.44	264,808.04
152	Kogi	Omala	ABEJUKOLO I	19,446	6.5	26,576	9.97	17	0.216	75.77	306,636.02
153	Kwara	Pategi	PATIGI 1	32,246	10.7	44,070	14.69	33	0.214	111.64	451,803.73
154	Kwara	Pategi	LADE 11	22,770	7.6	31,119	11.33	26	0.226	86.11	348,464.01
155	Kwara	Edu	LAFIAGI 11	41,824	13.9	57,159	17.10	46	0.216	129.96	525,925.38
156	Kwara	Kaiama	KAIAMA 11	36,296	12.1	49,605	15.87	37	0.210	120.61	488,095.66
157	Nasarawa	Awe	MAKWANGIJI	26,374	8.8	36,044	10.89	28	0.212	82.76	334,931.42
158	Nasarawa	Doma	UNGWAN MADAKI	109,661	36.6	149,870	49.46	111	0.212	370.95	1,501,169.73
159	Nasarawa	Lafia	AGYARAGUN TOFA	21,289	7.1	29,096	10.15	21	0.214	77.14	312,172.08
160	Niger	Magama	AUNA EAST CENTRAL	27,199	9.1	37,172	10.65	33	0.217	80.94	327,550.02
161	Niger	Lapai	EBBO/GBACINK U	19,158	6.4	26,183	8.73	19	0.210	66.35	268,498.75
162	Niger	Mariga	INKWAI	19,682	6.6	26,899	7.83	20	0.204	59.51	240,818.46
163	Niger	Tafa	IDDAH	23,724	7.9	32,423	11.32	23	0.211	86.03	348,156.45
164	Niger	Rijau	T/MAGAJIYA	17,338	5.8	23,695	6.91	17	0.200	52.52	212,523.06
165	Ogun	Egbado North	IJOUN	22,363	7.5	30,562	11.93	22	0.222	90.67	366,917.53
166	Ondo	Okitipupa	MAHIN 1V	26,612	8.9	36,370	13.21	31	0.238	100.40	406,285.04
167	Ondo	Akoko South West	OBA II	22,644	7.5	30,946	11.26	21	0.219	85.58	346,311.10
168	Ondo	Akoko South West	SUPARE II	26,750	8.9	36,558	13.34	29	0.228	101.38	410,283.31
169	Ondo	Akoko North West	ESE/AFIN	19,969	6.7	27,291	8.89	24	0.234	67.56	273,419.68
170	Ondo	Ilaje	UKPARAMA II	19,255	6.4	26,315	9.55	19	0.236	72.58	293,718.56
171	Osun	Ife South	OLODE	23,059	7.7	31,514	12.38	24	0.230	94.09	380,757.67
172	Osun	Aiyedade	OLUFI	194,069	64.7	265,227	92.55	187	0.220	694.13	2,809,002.40

173	Osun	Aiyedade	IJEGBE/OKE-ESO/OKE-OWU IJUGBE	29,370	9.8	40,139	16.30	30	0.230	123.88	501,320.68
174	Oyo	Iseyin	ADO-AWAYE	18,146	6.0	24,800	8.96	20	0.230	68.10	275,572.60
175	Oyo	Ibarapa North	IGANGAN I	24,406	8.1	33,355	13.15	25	0.228	99.94	404,439.69
176	Oyo	Kajola	AGBAAKIN I	27,120	9.0	37,064	13.73	29	0.228	104.35	422,278.10
177	Oyo	Ori Ire	ORI IRE VII	50,351	16.8	68,813	23.45	53	0.219	178.22	721,225.15
178	Oyo	Iwajowa	IWERE-ILE II	23,719	7.9	32,416	13.37	20	0.220	101.61	411,205.98
179	Oyo	Kajola	OLELE	60,801	20.3	83,094	27.95	57	0.213	209.63	848,315.69
180	Oyo	Kajola	KAJOLA	59,271	19.8	81,003	24.47	71	0.228	183.53	742,693.56
181	Oyo	Saki East	OJE OWODE II	20,464	6.8	27,967	10.47	18	0.216	79.57	322,013.96
182	Oyo	Itesiwaju	OTU II	19,260	6.4	26,322	9.81	17	0.216	74.56	301,715.08
183	Plateau	Langtang South	MABUDI	24,255	8.1	33,149	11.29	24	0.212	85.80	347,233.77
184	Plateau	Shendam	SHENDAM CENTRAL (A)	56,726	18.9	77,526	23.42	60	0.211	175.65	710,824.81
185	Plateau	Qua'an Pan	KWALLA MOEDA	23,509	7.8	32,129	11.21	23	0.213	85.20	344,773.30
186	Plateau	Wase	KUMBUR	25,005	8.3	34,174	12.19	21	0.207	92.64	374,914.06
187	Plateau	Langtang North	PAJAT	34,637	11.5	47,338	14.60	35	0.207	110.96	449,035.70
188	Plateau	Mangu	MANGU 11	21,259	7.1	29,054	9.31	21	0.207	70.76	286,337.15
189	Rivers	Khana	KONO/KWAWA	26,543	8.8	36,275	15.27	28	0.249	116.05	469,642.13
190	Rivers	Khana	SII/BETEM/KBA ABBE	29,128	9.7	39,808	16.14	32	0.251	122.66	496,399.74
191	Rivers	Khana	BOUE	22,013	7.3	30,085	13.63	22	0.250	103.59	419,202.51
192	Rivers	Asari-Toru	WEST CENTAL GROUP	21,152	7.1	28,908	13.59	21	0.253	103.28	417,972.27
193	Rivers	Okrika	OKRIKA V	29,710	9.9	40,604	17.34	31	0.249	131.78	533,306.79
194	Rivers	Khana	SOGHO	19,581	6.5	26,761	12.60	19	0.251	95.76	387,523.96
195	Rivers	Khana	OKWALI	17,333	5.8	23,688	10.98	17	0.250	83.45	337,699.45
196	Rivers	Etche	OKEHI	22,785	7.6	31,140	11.86	22	0.228	90.14	364,764.62

197	Rivers	Etche	OZUZU	21,682	7.2	29,632	13.27	22	0.240	100.85	408,130.39
198	Sokoto	Silame	KATAMI NORTH	23,921	8.0	32,692	10.39	19	0.192	78.96	319,553.49
199	Sokoto	Isa	ISA SOUTH	34,145	11.4	46,665	12.15	36	0.193	92.34	373,683.82
200	Sokoto	Kware	KWARE	40,986	13.7	56,015	14.00	44	0.193	106.40	430,582.18
201	Sokoto	Wurno	MARAFA	102,953	34.3	140,703	39.57	126	0.209	296.78	1,200,996.49
202	Sokoto	Gwadabawa	GWADABAWA	82,761	27.6	113,107	29.16	87	0.206	218.70	885,040.63
203	Sokoto	Tangaza	TANGAZA	23,584	7.9	32,231	10.74	20	0.194	81.62	330,318.04
204	Sokoto	Goronyo	GORONYO	23,359	7.8	31,924	9.98	23	0.196	75.85	306,943.58
205	Sokoto	Gwadabawa	GIGANE	28,706	9.6	39,232	11.44	34	0.206	86.94	351,847.15
206	Sokoto	Gada	KYADAWA/HOLAI	21,589	7.2	29,505	8.01	22	0.192	60.88	246,354.52
207	Sokoto	Illela	KYADAWA/HOLAI	22,680	7.6	30,996	9.12	20	0.189	69.31	280,493.53
208	Sokoto	Goronyo	RIMAWA	18,353	6.1	25,083	6.68	19	0.192	50.77	205,449.21
209	Taraba	Sardauna	GEMBU \B\	44,449	14.8	60,747	19.08	46	0.211	145.01	586,822.00
210	Taraba	Gashaka	SERTI \B\	42,383	14.1	57,923	17.94	43	0.208	136.34	551,760.31
211	Taraba	Donga	ASIBITI	32,198	10.7	44,003	13.06	34	0.210	99.26	401,671.66
212	Taraba	Wukari	HOSPITAL	140,379	46.8	191,851	61.69	149	0.216	462.68	1,872,364.76
213	Taraba	Bali	BALI B	21,626	7.2	29,556	9.62	19	0.204	73.11	295,871.47
214	Taraba	Gassol	SABON GIDA	27,540	9.2	37,638	11.52	28	0.207	87.55	354,307.62
215	Taraba	Gassol	MUTUM BIYU II	37,324	12.4	51,009	15.01	39	0.208	114.08	461,645.61
216	Taraba	Karin-Lamido	KARIM	23,651	7.9	32,323	10.44	20	0.200	79.34	321,091.28
217	Taraba	Lau	JEN ARDIDO	25,204	8.4	34,445	11.19	28	0.214	85.04	344,158.19
218	Taraba	Karin-Lamido	KWANCHI	17,089	5.7	23,355	7.06	17	0.204	53.66	217,136.44
219	Yobe	Gujba	GONIRI	18,854	6.3	25,767	7.71	20	0.202	58.60	237,127.76
220	Yobe	Bursari	GARUN DOLE / GARIN ALKALI	22,315	7.4	30,497	9.85	18	0.195	74.86	302,945.32
221	Yobe	Nguru	KANURI	48,043	16.0	65,659	21.89	55	0.211	164.18	664,387.49

222	Zamfara	Birnin Magaji	MODOMAWA EAST	20,449	6.8	27,947	9.50	24	0.216	72.20	292,180.77
223	Zamfara	Maru	DAN SADAU	25,443	8.5	34,772	9.54	31	0.215	72.50	293,411.00
224	Zamfara	Zurmi	BIRNIN MAGAJI	22,272	7.4	30,439	9.20	18	0.216	69.92	282,954.00
225	Zamfara	Bukkuyum	BUKKUYUM	20,576	6.9	28,121	8.45	23	0.209	64.22	259,887.10
226	Zamfara	Bungudu	RAWAYYA/ BELA	20,078	6.7	27,439	8.68	16	0.192	65.97	266,960.95
227	Zamfara	Kaura-Namoda	S/BAURA/S/M AFARA	32,965	11.0	45,052	12.95	35	0.200	98.42	398,288.52
228	Zamfara	Maradun	JANBAKO	26,625	8.9	36,388	11.58	27	0.201	88.01	356,152.97
229	Zamfara	Bakura	BIRNIN TUDU	25,674	8.6	35,087	8.77	32	0.212	66.65	269,728.98
230	Zamfara	Shinkafi	SHINKAFI SOUTH	33,943	11.3	46,389	13.38	34	0.193	101.69	411,513.54
231	Zamfara	Gummi	BIRNIN TUDU	20,259	6.8	27,687	9.58	21	0.210	72.81	294,641.23
232	Zamfara	Bungudu	TUDUN WADA	19,567	6.5	26,742	9.60	21	0.210	72.96	295,256.35
233	Zamfara	Talata Mafara	JANGEBE	25,805	8.6	35,266	9.24	29	0.201	70.22	284,184.24

Appendix 4

		Profit and Loss Account (Nigeria Naira)			
Distribution Companies	**Amount Invested in Naira at time of purchase (60%)**	**Dec-13**	**Dec-14**	**Dec-15**	**2016**
Abuja Electricity Distribution Plc	25,799,000,000	(13,789,334,000)	(25,971,035,000)	(41,972,588,000)	(47,447,920,000)
Benin Electricity Distribution Plc	20,215,000,000	(10,296,416,000)	(8,901,716,000)	(4,392,440,000)	(7,439,057,000)
Eko Electricity Distribution Plc	21,182,000,000	(11,118,156,000)	(6,461,882,000)	(6,577,375,000)	(28,662,720,000)
Enugu Electricity Distribution Plc	19,803,000,000	(8,866,863,000)	(9,340,784,000)	(26,426,928,000)	(31,091,648,000)
Ikeja Electric Plc	20,638,000,000	(6,852,382,000)	(12,109,708,000)	(28,616,172,000)	(65,636,304,000)
Jos Electricity Distribution Plc	12,852,000,000	(7,096,484,000)	(6,038,885,000)	(8,721,338,000)	(16,841,721,000)
Kaduna Electricity Distribution Plc	25,612,000,000	(4,846,239,000)	(13,095,912,000)	(12,088,470,000)	(17,904,725,000)
Kano Electricity Distribution Plc	25,612,000,000	(5,312,238,000)	(8,774,343,000)	(5,054,876,000)	(18,464,155,000)
Port Harcourt Electricity Distribution Plc	21,438,000,000	(13,517,063,000)	(7,331,698,000)	(14,173,604,000)	N/A
Yola Electricity Distribution Company Plc	19,506,000,000	(2,822,248,000)	(2,141,583,000)	(3,827,771,000)	(7,642,832,000)
Ibadan Electricity Distribution Company Plc	26,505,000,000	N/A	N/A	(11,200,000,000)	(24,900,000,000)

Author's computation from the analysis of the publicly available financial statement of Discos (2013-2016)

Exchange rate 1 USD =305.3 Naira

Appendix 5

List of techno-economic Simulation Assumptions

- Generic 1Mwhr Lithium-ion battery

Nominal Capacity (Ah) = 1670

Nominal Voltage (V) = 600

Lifetime = 15 Years

Capital cost = $700,000

O and M =$10,000/Year

Initial state of charge =100%

Minimum state of charge =20%

Throughput (kwhr) = 3,000,000

Roundtrip Efficiency =90%

Maximum Charge current (A) = 1670

Maximum Discharge current (A) = 5000

- **Generic flat plate PV**

Lifetime = 25 Years

Capital cost = $1/Watt

O and M = 1% of Capital Cost

Derating Factor = 80%

- **Generic large free converter**

Inverter Input

Lifetime =15 Years

Efficiency = 95%

Rectifier Input

Relative Capacity = 100%

Efficiency = 95%

- **Load Characteristics**

Community load with peak evening hours demand

Random Variability: Day-to-Day = 10%; Timesteps = 20%

- **Cluster Project Assumptions**

Project lifetime: 25 Years

Discount rate: 6% (based on provision of sovereign/development partners guarantee for risk mitigation)

Inflation Rate: 2%

Land assumed to be freely provided by the state and local governments

Annual Capacity constraint: 0%, 5%, 10%, 15% and 20% sensitivity scenarios

Cluster specific Solar Irradiation: NASA Surface meteorology and Solar Energy, horizontal radiation, monthly average values over 22 Years, available in HOMER software

Cluster specific Ambient temperature: NASA Surface meteorology and Solar Energy, Air temperature, monthly average values over 22 Years, available in HOMER software

The formula used for calculating the LCOE of is:

$$\frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

LCOE = the average lifetime levelised cost of electricity generation.

I_t = investment expenditures in the year t.

M_t = Operations and maintenance expenditures in the year t.

F_t = Fuel expenditures in the year t.

E_t = Electricity generation in the year t.

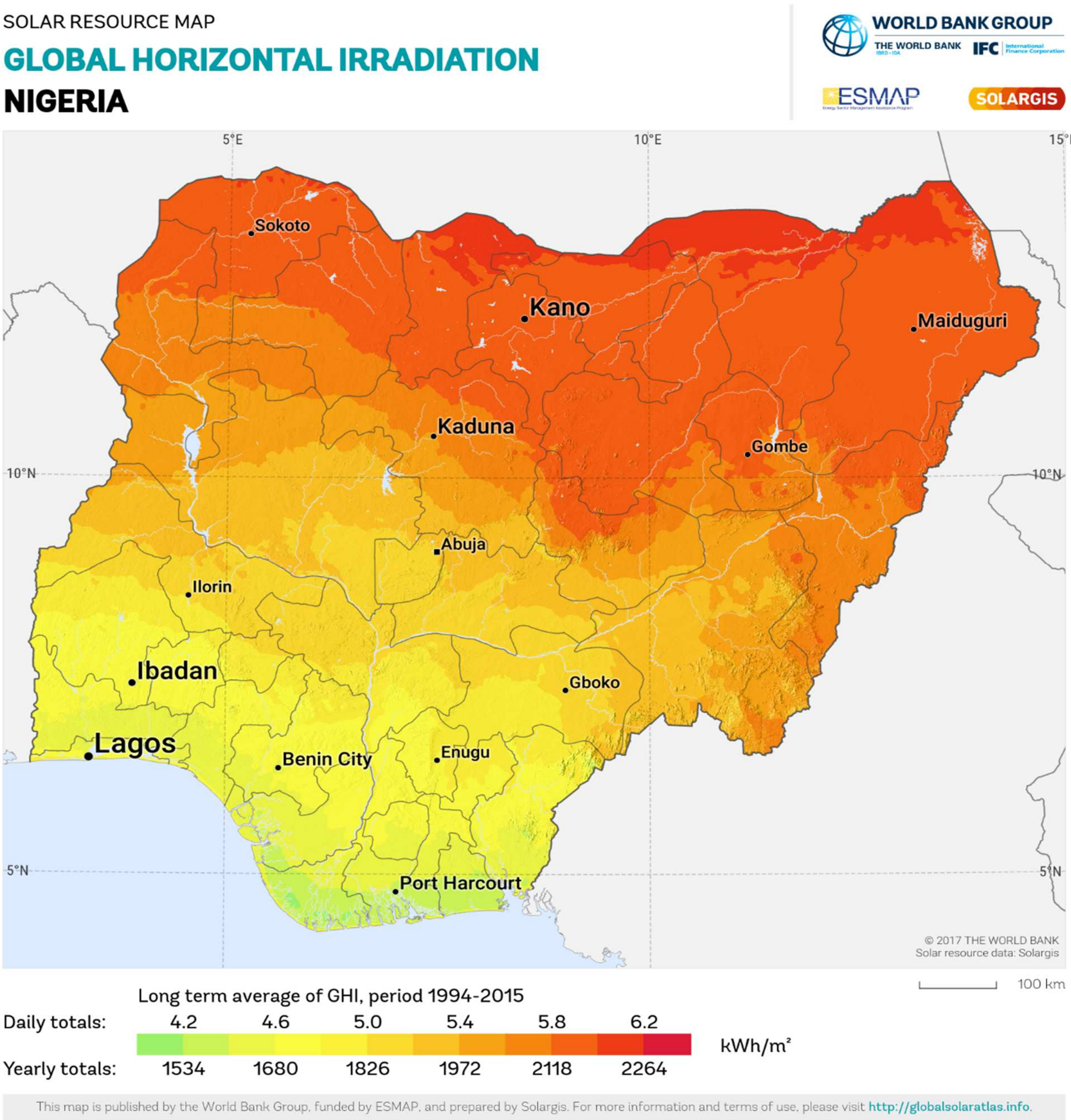
r = Discount rate; and

n = Life of the system.

APPENDIX 6

Consumer Cluster with Nightlight Emission and Electrified Schools (in purple)

<u>**SOLAR RESOURCE MAP OF NIGERIA**</u>



Map Source : https://solargis.com/maps-and-gis-data/download/nigeria/