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Electrification modelling for Nigeria

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Abstract

Reliable access to electricity still remains a challenge in many regions of Nigeria. For achieving a rapid electricity access for large geographic regions alternative electrification pathways apart from grid connection need to be taken into account. Therefore, sophisticated planning tools to determine techno-economic optimized electrification pathways are necessary. Here, an approach for such a tool is presented and combines GIS and energy system simulation tools. The approach is based on the identification of consumer clusters, determination of status of electrification and assignment of a suitable electricity supply option. Three options are taken into account: Grid extension, PV-hybrid mini-grids and solar-home systems (SHS). Within this study we have identified 47,489 consumer clusters for entire Nigeria and found that 46 % of the people living in these clusters are currently not supplied with electricity. A connection of all customers within a 20 km zone around the existing grid would have the largest impact with delivering electricity to 57.1 million people. Outside this grid zone, a population of 12.8 million is most suitably supplied by PV-hybrid mini-grids and 2.8 million by SHS. Therefore, a PV capacity in a range of 671 to 1,790 MW for mini-grids and 84 MW for SHS would be required.

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Keywords: Nigeria; electrification planning; spatial analysis; PV-hybrid mini-grid; solar-home systems.

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2. Introduction

Reliable access to electricity still remains a challenge in many regions of Sub-Saharan Africa as well as for many regions of Nigeria [1]. Advancing renewable energy technologies and storage systems open up novel perspectives for decentralized supply structures of electricity. As a consequence, new planning methods are required to account for innovative solutions comparing existing electrification options.

For achieving a rapid electricity access conventional options based on central power generation and the extension of large transmission grids need to be reconsidered, taking into account alternative electrification pathways for regions where access to electricity is still lacking or is insufficient [2]. Such alternatives are represented by hybrid mini-grids, which can combine different power generation and storage technologies to efficiently supply local loads [3]. The increased options and complexity of rural electrification underline the need of sophisticated planning tools to determine the techno-economically optimized electrification pathway. Only few tools exist for this target and their application is quite rare.

The presented approach enables comprehensive electrification planning by the use of GIS (geo-information systems) and energy system simulation tools. By that the conventional electrification approach via grid-extension is compared to electrification by hybrid mini-grids along several steps. For this study, a more simplified approach is applied for entire Nigeria in the context of the preparation of a policy directive “On the promotion of the use of energy from renewable sources and procurement of capacity” by the Federal Ministry of Power (FMP). This study supports the Policy Directive by providing quantities on the potential of photovoltaic (PV) systems for rural electrification by solar home systems (SHS) and PV-hybrid mini-grids for entire Nigeria. The attempt is complex because essential data on population distribution, the current status of electricity supply and load demands in rural areas is lacking and profound work-arounds need to be established. Therefore, a GIS database and spatial modelling is applied to understand where the consumers are located and whether or not they are reached by the grid or supplied with electricity already. Based on that, priority areas for different electrification approaches are assigned and capacity needs for PV-hybrid mini-grids and SHS are defined.

3. Methods

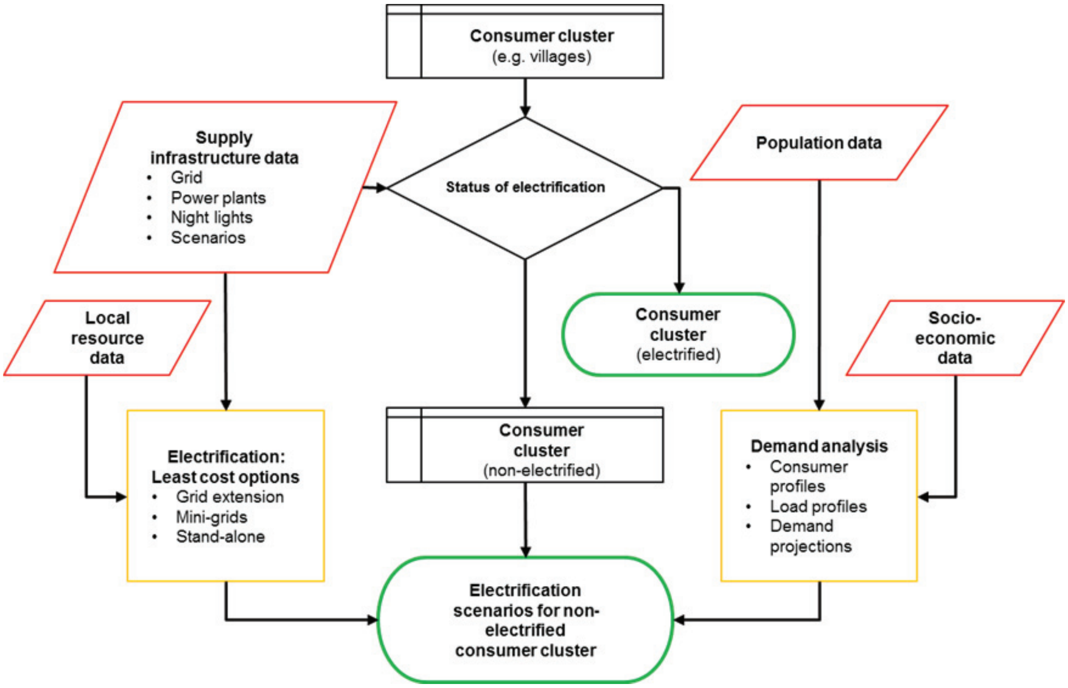
For this analysis, a combination of GIS tools, energy system simulation and literature analysis is chosen to derive an overview of the potential of SHS and PV-hybrid mini-grids for rural electrification in Nigeria. The approach is based on a step by step procedure: First, consumer clusters (such as villages, points of energy consumption, etc.) are identified. Second, the status of electrification for each consumer cluster is defined. Third, based on the location and population characteristics of each consumer cluster it is determined whether grid connection, PV-hybrid mini-grid or SHS are the most suitable electricity supply option. During this process, a large amount of different datasets is applied to ensure the accuracy of the analysis (Fig. 1).

3.1. Identification of consumer clusters

In order to identify populated areas for Nigeria, a population raster data set [4] is used as base source. This base source is extended with a school data set [5] and polling unit data set [6] as it is assumed that areas around both points are usually inhabited. Around each feature of these input data sets, a buffer zone of 500 m is added, which refers to a common threshold for connecting clusters in low voltage grids. Thereby, the spatial extension of consumer clusters is determined. Subsequently, the number of inhabitants is calculated per cluster. For this, first the population raster dataset [4] is taken into account. Second the population in smaller villages and towns (< 20,000 inhabitants) is scaled according to the average number of students per cluster (derived from school data [5]).

3.2. Determination of electrification status

The general approach to define the electrification status of the consumer cluster is based on two steps: Step 1 builds on night light imagery [7]. These images are satellite data which show light emissions during the night. These visible emissions are usually based on street lamps or other lights in villages or communities. A high amount of light



activity allows the assumption that any source of electricity exists in this area. Thus, consumer clusters with high night light emissions are defined as electrified. Step 2 uses qualitative data from the school data set [5]. For each school, information is provided whether the facility is grid connected or not. Each cluster was defined as electrified in case that a grid-supplied school was located within the cluster. Due to the lack or low quality of grid extension

Fig. 1. The flow diagram describes a holistic approach to assess different electrification options for developing regions with low electrification levels. This analysis requires a complex set of various input data (symbolized in red) and processing steps (symbolized in yellow). With the provided input data, the sample of clusters which need to be electrified is defined. For these locations, a demand assessment and the calculation of the most cost effective electrification option is carried out. As result each inhabited location is either already electrified, or the optimum electrification scenario will be suggested (symbolized in green).

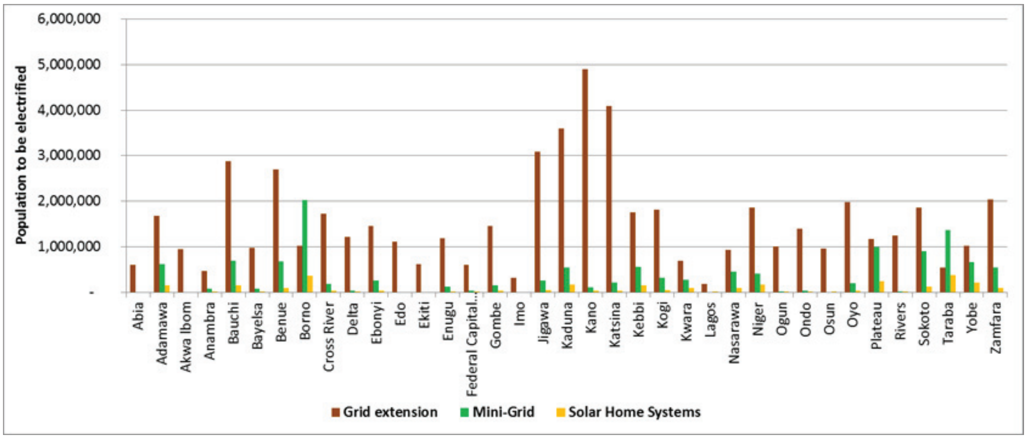
data for Nigeria, such data was not considered. Consequently, all consumer clusters with observable night light emission and information on grid connection from the school data set are considered as grid-connected.

3.3. Electricity supply options

For determining electricity supply options, three thresholds are defined. First, all clusters within a 20 km buffer zone of electrified clusters (grid-connected clusters) are assumed to be electrified via grid connection. Second, all clusters outside the grid extension area below a population of 1,000 are assumed to be electrified by SHS. Third, all remaining clusters are assumed to be electrified by PV-hybrid mini-grids. For projecting the necessary PV capacities for the areas supplied with PV-hybrid mini-grids and SHS, a load profile was derived based on [8]. An electricity consumption of 2.3 kWh/day (840 kWh/year) is assumed per household (average size of 5 persons) and a peak load of 350 W. The load profile is characterized by an evening peak, which is typical for rural villages [8].

4. Results and discussion

In total: 47,489 clusters including 171 of 181 million people of Nigeria (10 % of the rural population is assumed to live in very small rural settlements or to not even have a permanent settlement location so that they cannot be assigned to a certain consumer cluster) are identified. Of these clusters, an amount of 45,456 clusters are non-



electrified (95 %). However, in the non-electrified clusters only 83 out of 181 million people are living, which refers to a share of 46 %. The largest population without access to electricity lives in the states of Kaduna, Bauchi and Niger. By applying the predefined thresholds for electricity supply options the, following results are generated: A total of 34,446 clusters referring to an overall population of 57.1 million people are assigned for supply by grid

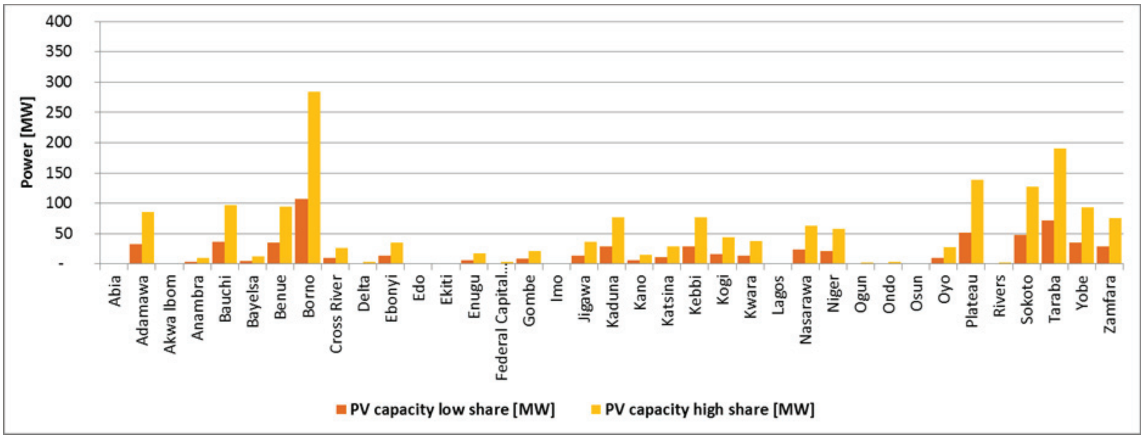
Fig. 2. Electricity supply options for non-electrified consumer clusters for all Nigerian states.

extension. The remaining clusters are to be electrified either by PV-hybrid mini-grids or SHS according to the population threshold of below 1,000 inhabitants. Consequently, 3,800 clusters with a population of 12.8 million are recommended for electrification by PV-hybrid mini-grids contrasted to 7,210 clusters with a population of 2.8 million recommended for electrification by SHS. An extension of the main grid and connection of all consumers within a distance of 20 km would have the largest impacts in the states of Kano, Katsina and Kaduna. Whereas electrification by PV-hybrid mini-grids would have largest impacts in the states of Borno, Taraba and Plateau (see Fig. 2).

For deriving the necessary PV capacities for electrification with PV-hybrid mini-grids, two scenarios are defined: A low renewable energy (RE) share scenario with a PV share of 75 % of the peak load and a high RE share scenario with a PV share twice the peak load. These two scenarios are applied to reflect PV-hybrid mini-grids with low or no battery storage capacities and PV-hybrid mini-grids with a significant share of battery storage capacities. The scenarios result in PV capacities of 263 Wp (low RE share) and 700 Wp (high RE share) per household. Per consumer cluster assigned for mini-grid supply only one PV-hybrid mini-grid is assumed. Finally, for the low RE scenario, an overall necessary PV capacity of 671 MW is derived compared to a necessary PV capacity of 1,790 MW for the high RE share scenario. Largest PV capacities are projected for Borno, Taraba and Plateau (see. Fig. 3). For SHS, a standardized PV capacity of 150 Wp per household was assumed resulting in a potential of 84 MW for the supply of 560,000 households.

5. Conclusions

With our approach, we offer a tool for developing techno-economically optimized renewable electrification strategies for Sub-Saharan Africa. Thus, we prove in this study the applicability of our electrification planning tool and provide valuable results for strategic electrification planning in Nigeria. Within this study, we identified all electrified and non-electrified clusters and determined their population in detail. Subsequently, an electrification approach was determined for each non-electrified consumer cluster based on pre-defined thresholds. A connection of all customers within 20 km of the existing grid would have the largest impact with delivering electricity to 57.1 million people. Outside this grid zone, a population of 12.8 million is most suitably supplied by PV-hybrid mini-grids and 2.8 million people by SHS. Special emphasis is put on the necessary capacities for PV-hybrid mini-grids and SHS. A required PV capacity of 671 MW (low RE share) and 1,790 MW (high RE share) is derived for electrifying villages by mini-grids. A PV capacity of 84 MW in SHS is required for delivering electricity supply



options to the remaining clusters. These results highlight the high potential for PV-based electrification in Nigeria. The results show a preliminary possible range of PV potential for mini-grid and SHS electrification. A considerable improvement of the results would be achieved by a detailed simulation of grid extension costs and detailed energy system modelling per cluster. These steps are planned to be conducted within further work steps under this research

Fig. 3. Indicative PV capacities for low RE and high RE scenario for all Nigerian states.

cooperation in the framework of the Nigerian Energy Support Program (NESP). This study is of high relevance for African-European partnerships as developed methodologies are transferred to Nigerian authorities through training and the overall approach is applicable for other African countries.

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