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Technology options for increasing electricity access in areas with low electricity access rate in Nigeria

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ABSTRACT

This study examines the least-cost technology option for increasing electricity access in two states in Nigeria where electricity access rate is below 20% i.e. Taraba and Yobe within a 10-year investment period. We employ the Network Planner – a web-based decision support program which integrates geospatial information with socio-economic, demographic and energy demand information, and compare three electrification options: grid-extension, mini-grid diesel-based system, and stand-alone option which uses solar PV and a small diesel generator. The result shows that grid-extension is the least-cost option for 98.7% and 89.5% of the demand centers in Taraba and Yobe respectively.

1. Introduction

1.1. Background

The importance of modern energy services to the socio-economic development of an economy has been extensively documented in the literature. Access to modern energy services, especially electricity, is closely related to improvements in other indices of human development such as health care, water supply, education, environmental sustainability, agricultural development, etc. [1–3]. However, millions of persons around the world, especially in rural areas of developing countries do not have access to electricity [4]. In Nigeria, only about 56% of the population had access to electricity in 2013 [5]. There is, however, much disparity in electricity access rates across the 36 states in Nigeria – with Lagos State having an access rate of 99.3% and Taraba State 10.9% (Fig. 1). This disparity is mainly because of:

(i) the disparity in population density across the states (see Fig. 2); and
(ii) the geographic coverage of the transmission lines – the transmission lines cover most areas in the south where gas-powered thermal generating facilities are located but not the North-Eastern part of the country which does not have any generating facility (see Fig. 3).

Recognizing the importance of electricity access to its socio-economic transformation, the Nigerian government has carried out comprehensive reforms in the electricity sector. One of the objectives of the reform is to improve reliability and access to electricity across the country with a view of attaining universal electricity coverage in the shortest possible time. In Nigeria, as in many other countries in sub-Sahara Africa, the most common approach for electrifying un-electrified communities is grid-extension. However, several studies in different parts of the world have shown that decentralized electrification, whether mini-grid or stand-alone systems, is gradually becoming an economically viable option for providing electricity to areas where extending the existing grid may be too expensive, physically impossible, or lead to gross under-utilization of electricity [7–9]. Irrespective of its high cost, extending the existing grid may still yield net economic returns if it serves areas that are densely populated and persons who can pay for the services to ensure optimal utilization of the electricity. Therefore, to achieve increased electricity access in Nigeria, rural electrification planners need to adopt a multi-facet approach which involves the combination of grid-extension and off-grid electrification in a manner that minimizes cost and maximizes electricity utilization.

Several energy planning models which possess different characteristics and can be applied to address diverse energy planning objectives have been developed and used extensively in the energy sector. An overview of some of these models can be found in Refs. [10–15]. Since rural areas in many developing countries are characterized by low access to electricity [16], some studies have approached electricity planning with the objective of increasing access to electricity at the country level, sub-national regional level, or in rural areas. The main objective of these studies is to increase access to electricity in the study area using a least-cost combination of technology options [17–19], [8]. Because of the interaction of the electricity

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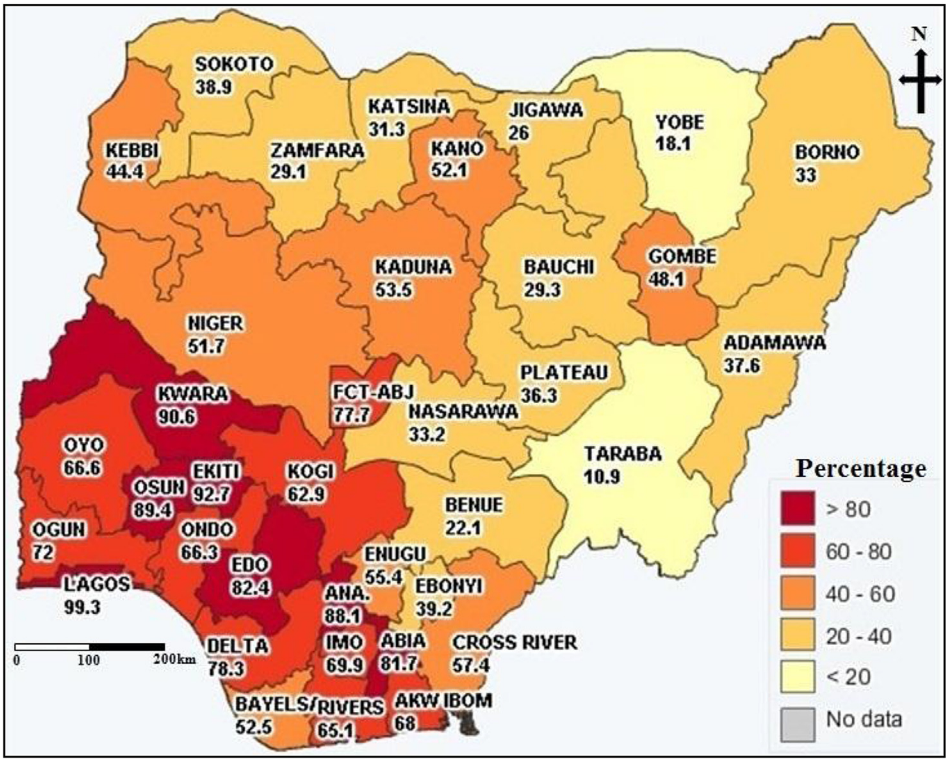

Fig. 1. Percentage of households with electricity access in the different States in Nigeria.
Source of data: National Population Commission [5].

sector with several other aspects of the economy, the objective of increasing electricity access is viewed in the context of techno-economic feasibility of technology options, and in terms of other socio-political, environmental, and governance factors [15]. The techno-economic aspects considers the operating capacity, financial viability, cost-effectiveness, attractiveness of the technology option to a potential investor, and the economic benefits of the option. The governance aspect considers whether the existing institutions in the country have the capacity to implement the proposed technology option; the socio-political aspect considers the acceptability of the proposed technology option, affordability issues as well as the development outcomes of the technology option such as local income generation, women empowerment, etc.; while the environmental aspect considers the adverse environmental effects of the technology option [15].

Some studies that have focused on increasing access to electricity in areas with low electricity access rate have adopted methods that choose the lower-cost option between extending the existing grid to deliver electricity and using off-grid electrification option to deliver the same amount of electricity [20–23]. The cost of extending the grid include the capital cost of constructing transmission and/or distribution lines to load centers with different levels of load factors, the potential transmission/distribution losses, as well as the cost of increasing the generation capacity; while the off-grid option covers the cost of using different locally-available resources for electricity generation to meet similar load levels. With this procedure, one can obtain: the specific distance; the level of demand; and the load factor under which off-grid electrification will be the lower-cost option. Kaijuka [24] used geographic information system (GIS) to visualize demographic information on location of households and institutions and used the information to project energy demand patterns and priority investment areas for rural electrification using grid or off-grid technologies in Uganda.

Parshall et al. [22] incorporated geospatial information on population settlement patterns into an electricity planning model to identify the least-cost technology option for providing electricity to different demand centers in Kenya where urban and rural electrification rate was 30% and less than 10% respectively. The study also applied the Kruskal's minimum spanning tree algorithm[1] to select a set of load areas that will minimize the total cost of grid-extension. The result of the study showed that under most geographic conditions, grid-extension was the lower-cost option especially in urban areas and rural areas with dense population. Sanoh et al. [25] employed a similar approach in Senegal to identify areas where decentralized electrification will be the lower-cost technology option for increasing electricity access. In such areas, the study also examined the lower-cost option between solar photovoltaic (PV)/diesel systems and diesel mini-grid options and the sensitivity of the options to different cost drivers. Similarly, Kemausuor et al. [26] applied the Network Planner (NP) – a web-based decision support tool to examine the cost of using different electrification technology options to provide electricity to communities in Ghana not connected to the electricity grid. The NP is based on the methods used by Parshall *et al.* [22].

1.2. Problem statement

The Electric Power Sector Reform Act 2005 established the Rural Electrification Agency (REA) and mandated it to develop a comprehensive Rural Electrification Strategy and Plan (the Plan). The Plan was expected to incorporate information regarding the most appropriate technology option (between grid-extension and decentralized electrification) for electrifying each unelectrified

[1] In Graph Theory, a spanning tree is a connected graph that connects all points on graph without any cycle. A minimum spanning tree (MST) is a spanning tree that has the smallest weight. The Kruskal's MST algorithm is an algorithm for obtaining a minimum spanning tree developed by Joseph Kruskal in 1956.