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Potential and econometrics analysis of standalone RE facility for rural community utilization and embedded generation in North-East, Nigeria

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ABSTRACT

This study carried out a comprehensive renewable energy resource assessment for 6 sites in North-East, Nigeria. The main aim was to assess the feasibility and economic viability of wind and solar resources for hybrid energy system that can provide sustainable electricity for rural communities unconnected to the national grid. Rural communities made up of 200 homes, a school and health center was conceived. Specific electric load profile, of 358 kWh per day, with 46 kW primary and 20 kW deferrable peak loads, was planned to match the rural communities. The daily data utilized were obtained from the Nigeria Meteorological Department and comprise of mean wind speeds, global solar radiation, sunshine hours air temperatures, relative humidity for periods spanning 1987–2010. The assessment of the design that will optimally meet the daily load demand with LOLP of 0.01 was carried out by considering 3 standalone applications of PV, wind and diesel, and a hybrid design of wind-PV. The diesel standalone system was taken as the benchmark. The result showed that the hybrid system gave the most cost-effective alternative at 5 different locations (Potiskum, Nguru, Bauchi, Ibi and Yola). However, for Maiduguri, the wind standalone system proved to be the optimal means of renewable electricity in terms of life cycle and levelised costs. The values ranged between $0.17/kWh for Maiduguri (Wind) and $0.40/kWh for Yola (hybrid). This is competitive with grid electricity, which is presently about 0.10/kWh.

1. Introduction

Nigeria has an area of 923,768.00 sq km (comprising 910,768 km^2 of land and 13,000 km^2 of water) and lies between latitude 4° North and 14° North of the equator and longitudes 3° East and 14° East of the Greenwich meridian. This is entirely within the tropical zone (Independent Statistics and Analysis, 2013; The Nigerian Geography, 2013). Only about 33% or 300,550 km^2 of this land mass is arable, while 3.1% or 28,234 km^2 is recorded to be under permanent crops. An approximate of 2820 km^2 (0.31%) is under irrigation (CIA, 2009). The practicing farmers association of Nigeria (PFAN) carried out a survey in which it was stated that about two third of Nigeria's arable land resource remain underutilized while the little utilized have not been put to use for commercial purposes (PFAN, 2008). The reasons attributed to this range from a lack of adequate energy source to drive irrigation especially in the northern regions which have lower rainfall duration in comparison with the south. Also with increase in fuel prices, energy from fossil based generators has escalated. While a lack of skilled extension work force attributable to the chronic energy poverty in these locations have cumulatively resulted in the decrease in contribution of agriculture to the overall GDP of the country.

In Nigeria presently there is a huge reliance on diesel consumption for electricity generation. The Central Bank of Nigeria in 1985 gave an estimate of 8,771,863 tons of crude oil equivalent (Onyebuchi, 1989) as annual national consumption. This value matches about 180,000 barrels of crude oil on a daily basis. This figure has persistently heightened ever since. In addition, the Department for Petroleum Resources (Chineke & Igwiro, 2008) detailed that 78% of the total energy consumption in Nigeria is petroleum based. The offshoot of such practice is injurious to the environment and humans. In this regard, the best alternative energy source are renewable energy sources, which have been recognized and accepted as an effective means of attaining sustainable development (Bullis, 2009; Innovations for Improving Efficiency, 2009).

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In view of the above, a hybrid renewable energy system (HES) characteristically made up of two or more renewable energy sources incorporated together to improve system efficiency is conceptualized and analyzed. However, several forms of hybrid energy systems exist. Some are designed in a manner as to make the most use of renewable resources in a mix with conventional energy sources resulting in a system with lesser emissions than conventional standalone fossil-fueled technologies. This gives rise to a reduction in the depletion rate of fossil fuels, as well as presenting an opportunity to furnish remote rural areas, cut-off from the central grid, with modern energy (Kanase-Patil, Saini, & Sharma, 2010). Renewable systems have also been reported to be adequately suited to rural areas due to their simplistic constructions as well as efficacy (Ngala, Alkali, & Aji, 2007). The simple hybrid system proposed in this study is composed of a wind generator, PV modules and batteries. The energy stored in batteries could be directly used to meet Direct Current (DC) loads, while for Alternative Current (AC) loads a suitably sized inverter must be utilized. There nonetheless, remains the complication brought about in combining two different energy sources making HES more difficult to analyze.

2. Review of some existing studies

A number of researches have focused on the prospect of hybrid Renewable Energy (RE) system for power generation in Nigeria. Some researches probed the potential of generating electricity either in standalone hybrid format or as grid-connected power systems. Others investigated the use of RE for telecommunications base stations in remote locations and individual residential apartments in city centers. Furthermore, a number of studies focused on the optimal performance of different hybrid system configurations, while contrasting their internal rate of return with conventional diesel standalone (DSA) systems. (Abatcha, Jumba, & Maijama, 2011; Agajelu, Ekwueme, & Obuka, 2013; Mbakwe & Iqbal, 2011; Ngala et al., 2007; Nwosu, Uchenna, & Madueme, 2012).

However, majority of the previous studies were basically centered on analyses for specific applications without a spotlight on a community wide analysis that distinctively establishes the technical and econometric viability of RE for rural energy projects. Most of the analyses also ignored the effects of other variables on the PV system such as relative humidity, air temperature, atmospheric pressure and wind speed. Also the place of the battery and the system level of reliability in terms of LOLP were also not considered by many of the existing studies. This has placed a limitation on the application of the aforementioned studies in terms of their ability to give precise and accurate data to steer investors' interest and motivate national policy initiatives toward the adoption of renewable HES for power generation. Based on this therefore, this study focused on the design of an optimal PV and wind system that adequately and precisely resolves the techno-economic viability of employing HES for community power generation. It employed the RETScreen® software architecture for the feasibility analysis and the HOMER® software for the optimization.

3. Materials and method

3.1. Data collection

The twenty-four years (1987–2010) daily global solar radiation and daily wind speed data that were engaged in this research were obtained from the Nigeria Meteorological agency (NIMET), Oshodi, Lagos, Nigeria. This study centers on a design for rural communities in north east Nigeria, with 200 homes, having a school and community health center. The location parameters and location of the selected sites are as shown in Table 1 and Fig. 1. Cumulative 25 kW wind turbines ranging between 2 and 17 turbines in accordance with the wind speed profiles of each site were utilized (see Table 4). Also, cumulative solar panels ranging between 105 kW and 140 kW (see Table 5) were utilized, while a diesel generator of 35 kW was also employed for comparison purposes.

Table 1
Location parameter of the studied sites.

S/N	Geopolitical zone	State	Sites	Latitude (°N)	Longitude (°E)
1		Borno	Maiduguri	11.8333	13.1500
2		Bauchi	Bauchi	10.5000	10.0000
3		Yobe	Potiskum	11.7333	11.1500
4		Yobe	Nguru	12.8750	10.4550
5		Adamawa	Yola	9.2300	12.4600
6		Taraba	Ibi	8.1850	9.7450

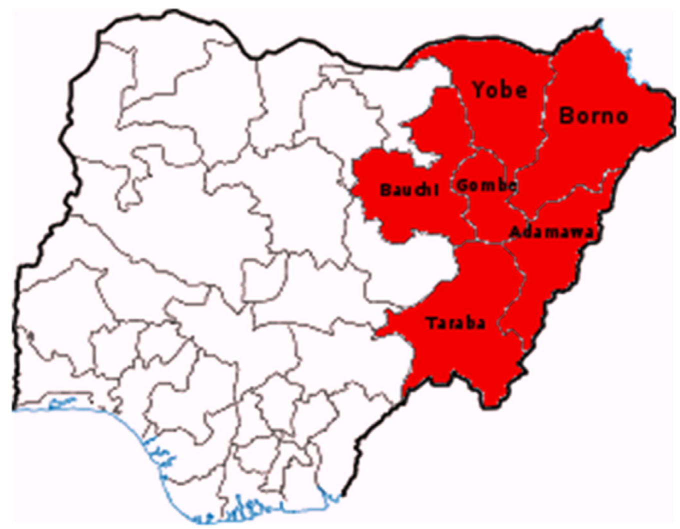

Fig. 1. Map of Nigeria highlighting the north eastern states (http://commons.wikimedia.org/wiki/File:Northeastern_State_Nigeria.png).

Table 2
General wattage chart for some household appliances.

Power rating	Household appliance
24 watts	42″ ceiling fan (low speed)
55–90 watts	19″ CRT television
150–340 watts	Desktop Computer & 17″ CRT monitor
60 watts	60-watt light bulb (incandescent)
18 watts	CFL light bulb (60-watt equivalent)

3.2. Load calculation

The load profiles for rural communities isolated from the national grid cannot be retrieved from the electric utility's company database, although electricity usage among rural families in developing nations is relatively low, at an average of 1 kWh/day per home (Meier, Tuntivate, Barnes, Bogach, & Farchy, 2010). This has been attributed to a number of factors, such as unavailability of expensive appliances, and high rate of poverty. Statistics for electricity also show that 96 kWh annually is required per person in rural areas (Energy For All, 2011). This is equivalent to about 315 kWh per day for the studied community of 200 homes in north east Nigeria. Hence the energy demand of the rural communities was therefore estimated via the analyses of the individual power rating of the appliances in use in rural homes. The assumed average electricity consumption value arrived at and utilized is 1.4 kWh per day per home. The mode of analysis is presented in Tables 2 and 3 (General