Renewable and Sustainable Energy Reviews 74 (2017) 474–490

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Sustainable energy development in Nigeria: Wind, hydropower, geothermal and nuclear (Vol. 1)

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ARTICLE INFO

Keywords:
Nigeria
Sustainability
Wind
Hydropower
Geothermal
Nuclear

ABSTRACT

In Nigeria, lack of adequate power supply has been recurrently cited as a hindrance to economic growth. This article provides an in-depth review on the wind, hydropower, geothermal and nuclear energy options in Nigeria, for a sustainable development of its power sector. The potential, current developmental stages, and prospects of each of the aforementioned energy conversion techniques, in the Nigerian context, are presented. The study reveals that although available data for each considered renewable energy option suggest renewable energy holds some potential, these data are not sufficient to make definitive global assessments of the country's prospects in this sector. Ground measured wind data are sparse and not consistent with satellite data. Hydropower resource databases have not been updated in a very long time. Geothermal records are only available for locations where oil explorations were previously performed. While these data might be useful for some local assessments, using them for global quantitative estimations would be misleading. A countrywide resource mapping across all technologies is required for a reliable outlook of sustainable energy development in Nigeria.

1. Introduction

The global response to climate change has been an augmentation of renewables' share in power production facilities with estimated 13% and 25% share recently reported in the United States and Germany respectively [1]. In developed countries, a sustainable energy mix has driven renewable energy considerations. However, in developing countries, the push for sustainable energy is mostly bolstered by the need to combat energy shortage in order to encourage development in the rural areas. Nigeria, Africa's richest economy and most populous nation, is a developing country with an economy largely supported by its huge oil production capacity. Ironically, the country has a meager electrical power density of about 33 W per person [1] which is considered one of the lowest in Africa. The huge gap between the country's energy demand and current production capacity suggests that a huge market is available in its power industry. Based on the country's current population of circa 180 million, electrical power capacity of about 5000 MW [2,3] and a conventional gas power plant capital cost of USD 1/W [4], it is estimated that the country would require about USD 150 billion and USD 600 billion in capital to attain the power density in South Africa and USA respectively. Nigeria with an expected 2015 gross revenue of about USD 18 billion [5] cannot afford to invest such a lump sum in its power sector.

Undoubtedly, Nigeria requires private investors to build its energy sector. However, low transmission capacity and frequency instabilities in the grid network demands decentralized energy solutions to the country's energy issues. The sustainable energy options readily fit this criterion with an added advantage of reduced pollution. On the other hand, Nigeria's technical and economic potential for sustainable energy has not been met with substantial development in its renewable energy portfolio.

Besides hydropower, the country does not have any large renewable

Abbreviations: CENER, Centro Nacional De Energias Renovable; CERT, Center for Energy Research and Training; DPR, Detailed Project Report; DU, Depleted Uranium; EWP, Endurance Wind Power; FiT, Feed in Tariff; HEU, Highly Enriched Uranium; IITA, International Institute of Tropical Agriculture; IAEA, International Atomic Energy Agency; LCOE, Levelized Cost of Energy; LEU, Lowly Enriched Uranium; MNSR, Miniature Neutron Source Reactor; NAA, Neutron Activation Analysis; NAEC, Nigeria Atomic Energy Commission; NASA, National Agency for Space Administration Surface Meteorology; NCCE, National Commission for College of Education; NERC, Nigerian Electricity Regulatory Commission; NIMET, Nigerian Metrological Agency; NOAA, National Oceanic and Atmospheric Administration; NRCRI, National Root Crops Research Institute; O & M, Operation and Maintenance; SHESTCO, Sheda Science and Technology Complex; SHP, Small Scale Hydropower

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http://dx.doi.org/10.1016/j.rser.2016.11.162
Received 26 September 2015; Received in revised form 14 August 2016; Accepted 12 November 2016
1364-0321/

based power plant contributing to its national grid and despite the huge energy market prospects, challenges such as lack of an effective bureaucracy, resource assessment data, awareness, enabling policies and skilled manpower have heightened investment risk and hence, discouraged potential investors. From an academic perspective, little can be done about the country's ineffective bureaucracy, but the first step in solving the other mentioned issues is to develop an understanding of the country's sustainable energy status with an overview of its local industry. Establishing the potential of each sustainable energy option via a compilation of resource data is the first point of call. A critical look into this data can then be used to suggest adequate policy and training measures.

This article is the first of two volumes which aims to provide a comprehensive overview of Nigeria's sustainable development. The present paper covers the wind, hydropower, geothermal and nuclear energy options in Nigeria. For each energy option, we construct our review by compiling the energy resource available in the country from data available in existing literature and then conduct a survey to establish the current local developmental status. Prospects of each technology are then deduced in tandem with favorable policy recommendations.

2. Wind

Wind power is generally considered as one of the most economically feasible renewable energy sources based on its Levelized Cost of Energy (LCOE) [1]. This has undoubtedly been an attraction to huge investments globally. In 2014, approximately 32% (USD 99.5 billion) of the USD 310 billion total investments recorded in the clean tech industry were centered on the wind sector taking the total installed capacity to 369,900 GW [6]. Notably, the low cost of wind power is tied to the frequent availability of wind resource, at relatively high speeds, in the location of installation. In 2009, the European Wind Energy Association revealed that the cost of wind generated power could rise from about 0.05€ in coastal areas, to 0.1€ in low wind areas [7]. This is a huge margin and the basis for which spatial and temporal wind resource assessment is typically the first step in implementing wind power generation [8].

In Nigeria, a reasonable amount of work has been carried out on the characterization of wind speed and pattern in order to identify the best locations for wind energy conversion. Studies on the country's wind resource assessment can be classified into: regional and countrywide investigations (> 10 locations). Most of the data used in these studies were sourced from the Nigerian Metrological Agency (NIMET) [9], while other sources include the NIMET owned Agro-meteorological and Statistics Department of National Root Crops Research Institute (NRCRI), International Institute of Tropical Agriculture (IITA) [10] and public universities. The following sections summarize these studies. The regional investigations are segmented according to the geopolitical zones in Nigeria while the nationwide investigations are classified according to the measurement time and period adapted.

2.1. Regional studies

2.1.1. South-West

The wind speed profile in Abeokuta (7.108°N, 3.20°E) and Ijebu (6.50°N, 3.56°E), both located in Ogun state, have been assessed by Ajayi et al. [11] and Amoo [12]. Ajayi et al.'s [11] evaluation was based on NIMET's measurements over a period of 24 years (1987–2010), at a height of 10 m. According to their report, the averaged wind speed in Abeokuta and Ijebu Ode are 2.5 m/s and 3.4 m/s respectively while, the maximum wind speeds are 5.2 m/s and 6.9 m/s respectively. Using this data, Ajayi et al. [11] estimated the capacity factor of a wind turbine with cut in speed of 3.5 m/s, hub height of 80 m, and rated output speed of 11.5 m/s to be 1.6% and 9.55% in Abeokuta and Ijebu Ode respectively. The sepcific cost of wind energy in those locations using the turbine with that specification was estimated to be 0.47 €/kW h in Abeokuta and 0.08 €/kW h in Ijebu Ode. Similarly, based on the NIMET data for a 20 year period (1990–2010), measured at a height of 10 m, Amoo [12] reported the average wind speeds in Abeokuta and Ijebu Ode as 2.54 m/s and 3.44 m/s respectively as well as the maximum wind speeds in Abeokuta and Ijebu Ode to be about 4.5 m/s and 7 m/s respectively.

In Akure (7.17°N, 5.18°E), Okeniyi et al. [13] performed a wind assessment based on data collected by NIMET, at a height of 10 m, over an 11 year period (1999–2009). Their report suggested that Akure's mean wind speed and power density are 2.7 m/s and 18.51 W/m^2 respectively. In addition, their outcomes also indicated that the rainy season is windier (2.76 m/s average wind speed) than the dry season (2.63 m/s average wind speed). Using the wind profile exponent equation and a correlation suggested by Justus et al. [14] to estimate the roughness factor, Okeniyi *et al.* [13] calculated the wind speed as a function of height. Results showed that at a hub height of 80 m, wind speeds could climb up to 5.5 m/s and the capacity factor of the wind turbine adapted could reach 7.51%. To buttress Okeniyi et al.'s findings, Ajayi et al.'s [11] assessment based on NIMET's measurements at a height of 10 m over a period of 24 years (1987–2010) reported an average wind speed of 2.2 m/s and a mean power density between 3.6 and 37.2 W/m^2 in Akure. Their analysis also suggested a capacity factor of a wind turbine operating at a hub height of 80 m to be 7.09% and a specific energy cost of 0.11 €/kW h.

Furthermore, Ajayi et al. [11] assessed the potential of wind power in three locations within Lagos State: Lagos Island (6.26°N, 3.25°E), Ikeja (6.45°N, 3.40°E), and Marina (6.26°N, 3.25°E), based on NIMET's measurements over a period of 24 years (1987 – 2010), at a height of 10 m. According to their report, the averaged wind speed in Lagos Island, Marina and Ikeja are 5.1 m/s, 3.8 m/s and 4.6 m/s respectively while, the maximum wind speeds in those locations are 8.6 m/s, 6.0 m/s and 6.9 m/s respectively. The specific cost of wind energy in those locations using a turbine with a 80 m hub height was estimated to be 0.02 €/kW h in Lagos Island, 0.02 €/kW h in Ikeja and 0.08 €/kWh in Marina. Capcity factors in those locations were reported as 42.26%, 8.76% and 30.67% respectively. However, it is important to note that based on our evaluation of NIMET's reported stations, the organization does not have any data stations located in Marina and Lagos Island.

Wind speed was also assessed in Ibadan (7.43°N, 3.90°E), located 130 km northeast of Lagos, by Fadare [15]. This analysis was based on data measured by the IITA, at a height of 10 m over a period of 10 years (1995–2004). Annual average and maximum wind speeds of 2.748 m/s and 3.841 m/s respectively were reported. Their data was used to estimate the wind power density of Ibadan to be about 12.555 W/m^2 - positioning Ibadan as a low wind speed region.

2.1.2. South East

In the South Eastern geo-political zone of Nigeria, wind resource mapping have been carried out in Umidike (5.48°N, 7.547°E) [16,17], Nsukka (6.80°N, 7.39°E) [18], Enugu (6.47°N, 7.56°E) [17,19], Owerri (5.48°N, 7.03°E) [20,21], and Onitsha (6.10°N, 6.47°E) [21].

In Umudike, Oriaku et al. [16] deduced from the 10-year (1994–2003) data collected by NRCRI, at a height of 10 m, that the region has a mean wind speed of 2.31 m/s, with a 98% chance of obtaining a 2.0 m/s hourly wind speed. Their study also suggested that the region's highest and lowest extractable wind resources, at that hub height, are 11.3 kW (in August) and 6.5 kW (in November) respectively. This analysis was corroborated by Asiegbu and Iwuoha's [17] report which utilized the 10 year data from the same source (NRCRI) and suggested an average regional wind speed of 2 m/s, at a height of 10 m.

Asiegbu and Iwuoha went on to suggest that in Umudike, an economically viable height for wind energy conversion is about 67 m. This suggestion was based on an estimation of the height where wind speeds would reach 5.26 m/s, using the wind profile power law and an