Renewable and Sustainable Energy Reviews 48 (2015) 336–346

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Current status and future prospects of renewable energy in Nigeria

Abubakar Sadiq Aliyu [a,e,1], Joseph O. Dada [b,c,*,1], Ibrahim Khalil Adam [d]

[a] Physics Department, Universiti Teknologi Malaysia, 81310 Skudai, Malaysia
[b] Manchester Institute of Biotechnology, School of Computer Science, University of Manchester, 131 Princess Street, M1 7DN Manchester, UK
[c] Electrical and Computer Engineering, Faculty of Engineering, Elizade University, P.M.B 002, Ilara-Mokin, Ondo State, Nigeria
[d] Department of Biochemistry, Faculty of Science, Nasarawa State University, P.M.B 1022 Keffi, Nigeria
[e] Department of Physics, Faculty of Science, Nasarawa State University, P.M.B 1022 Keffi, Nigeria

ARTICLE INFO

Article history:
Received 5 December 2014
Received in revised form
11 March 2015
Accepted 26 March 2015
Available online 22 April 2015

Keywords:
Nigeria electricity crisis
Renewable energy resources
Biomass
Solar energy
Hydropower
Wind energy

ABSTRACT

Nigeria is faced with chronic electricity crisis that has resulted in the crippling of most sectors of the economy. It is estimated that only 40% of Nigerians are connected to the national grid and the connected population are exposed to frequent power outages. Nigeria's electricity grid is mainly powered by large hydropower and depleting hydrocarbon resources. Fossil-based electricity generation contributes not only to increase in carbon footprints, but also exposes the country to changes in price of petroleum resources and political instability from the oil producing region of the country. The country is blessed with abundant Renewable Energy (RE) resources that have not been fully exploited; these renewable resources have the potentials to change the status quo of power generation and consumption in the country. Availability of Renewable Energy Sources (RESs) in all parts of Nigeria has been demonstrated in several studies. However, there is presently no comprehensive review of RE development in Nigeria. This contribution aims to fill this gap by focusing on the current status and future prospects of RE in Nigeria as well as identifying the key challenges confronting full scale RE development in the country. We discussed the existing government policies and legislations, and proposed others that can help speed up the adoption of RE in Nigeria. We also compared RE development in Nigeria with four other sub-Sahara African countries. We hope that this paper will stimulate further research on how to address the energy crisis in Nigeria using the RESs.

Contents

* Corresponding author at: Electrical and Computer Engineering, Faculty of Engineering, Elizade University, P.M.B. 002, Ilara-Mokin, Ondo State, Nigeria.
E-mail addresses: josephodada@gmail.com, joseph.dada@elizadeuniversity.edu.ng (J.O. Dada).

[1] These authors (AS Aliyu & JO Dada) contributed equally to this work, IK Adam contributed with discussions on Biomass/Bioenergy (3.4).

http://dx.doi.org/10.1016/j.rser.2015.03.098
1364-0321/

1. Introduction

The industrial growth and development of any nation are directly proportional to energy resources at its disposal. Energy resources provide not only economic power, but also play a critical role in any modern society. Nigeria is endowed with abundant conventional (fossil fuel) energy resources, such as oil, gas, coal, etc. These sources have predominantly contributed over 90% of the country's income and also dominate the fuel sources for electrical energy production and other energy needs of the populace.

Electricity, which was first generated for public use in Nigeria in 1896 is heavily dependent on the fossil fuel sources. Although it has been generated for over a century, electricity demand in Nigeria is at present far more than the supply, thereby affecting the country's socio-economic and technological development [1,2]. Nigeria is the most populous country in Africa, with population of over 155 million people[3] and the majority of the citizens are living below the $1.0 per day poverty level [4]. Only 40% of Nigeria's population is connected to the national electricity grid; the connected population faces power problems 60% of the time [1,5]

The energy crisis has crippled the nation's industrial sector, which claimed it needed 2000 MW (e) to run in 2009, and the Manufacturers Association of Nigeria (MAN) says it spends more than N 1.8 billion (US $ 11, 340 million) weekly in the running and maintenance of power generators [6]. The use of these generators in the industries has resulted in high cost of energy; since energy cost constitutes 40% of the production cost in Nigeria. At present, the cost of production in Nigeria is nine times higher than that of China [7].

The prevalent energy crisis has therefore put enormous pressure on the economic growth and development in the country. In addition to that, the continuous depletion of the conventional energy resources, unstable oil price in the international market, increasing demand to reduce carbon footprints and attempt by the developed and emerging worlds to seek other forms of energy sources to meet their energy needs will in the foreseeable future lead to a considerable reduction in income accrued to the nation from its petroleum resources. The sustainability of Nigeria as a nation will therefore be at risk unless other sources of energy are exploited to block the loopholes in the nation's income due to the dwindling income generated from the fossil-based sources, and to provide energy sources for electricity generation in the country.

The over-dependence of the energy sector on petroleum that has slowed down the development of alternative fuels [8,9] must be reversed. There is the need for diversification to achieve a wider energy supply mix, which will ensure greater energy security for Nigeria. The way forward is the exploration of the RESs, such as solar, wind, hydro, biomass, etc., which are also abundant in nearly all parts of the country. RESs are sustainable, limitless and environment friendly [10]. The potential of RESs in Nigeria is about 1.5 times that of fossil energy resources in energy terms [11]. RESs have significant potential to improve and make a difference on the low level access to electricity in Nigeria [12].

The Nigerian Government has recognized the important role the RE would play in overcoming the present energy crisis and therefore intensifies its efforts by promoting the RE in the country through development of various energy reforms, policies and legislations. The research communities are also not left out in the quest to pursue the RE development in Nigeria as demonstrated in the large body of research works that have been carried out on RE. Notable among these are the work of Udoakah and Umoh [13] on meeting the energy needs of Nigeria using RE, the work of Shaaban and Petinrin [12] on tapping of RE potentials for development of useful and stable electric energy supply in Nigeria. It also includes the work of Oyedepo [14] that examined the perspective of energy efficiency and RE for achieving a sustainable development in Nigeria. Other studies are Ohunakin and colleagues [15] on the utilization of solar energy as RE option in Nigeria, Mohammed and colleagues [16] on the potentials of bioenergy resources for bioelectric power generation in Nigeria and various works on wind energy potentials in different parts of Nigeria [17–21]. Further works on solar energy potentials can be found in [22–27] and small hydropotentials in [28–30].

Although these studies have demonstrated the availability of RESs in all parts of the country, there is presently no comprehensive review of RE development in Nigeria. This contribution aims to fill this gap by focusing on the current status and future prospects of RE in Nigeria as well as identifying the key barriers confronting the utilization of the full potential of RE in the country. We also discussed the existing government policies and legislations, and proposed others that can help speed up the adoption of RE in Nigeria.

2. Energy reserves and utilization in Nigeria

The primary energy sources are mainly utilized for electricity generation, transportation, heating and cooking in Nigeria. Energy

Table 1
Nigeria's RE reserve per capacity as at December 2005 [4,31].

Energy source	Reserves
Large hydro	11,235 MW
Small hydro	3500 MW
Animal waste	61 million tons/yr
Crop residue	83 million tons/yr
Solar radiation	3.5–7.5 kwh/m^2-day
Wind	2–4 m/s at 10 m height
Wave and tidal energy	150,000 TJ/(16.6 × 106 toe/yr)

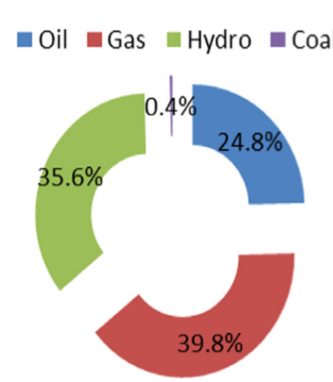

Fig. 1. Percentage contribution for the energy sources in Nigeria as of 2001 [8].

Table 2
Nigeria's power generating plants and their capacity utilization [35,36].

Power station	Type	No. of Units	Year of construction	Age (Yrs)	Installed capacity (MW)	2011 Available Capacity (MW)	% Contribution to the grid
Kainji	Hydro	12	1968	43	760	480	14.3
Jebba	Hydro	6	1985	26	540	450	13.4
Shiroro	Hydro	6	1989	22	600	450	13.4
Egbin	Thermal	6	1986	25	1320	1100	32.8

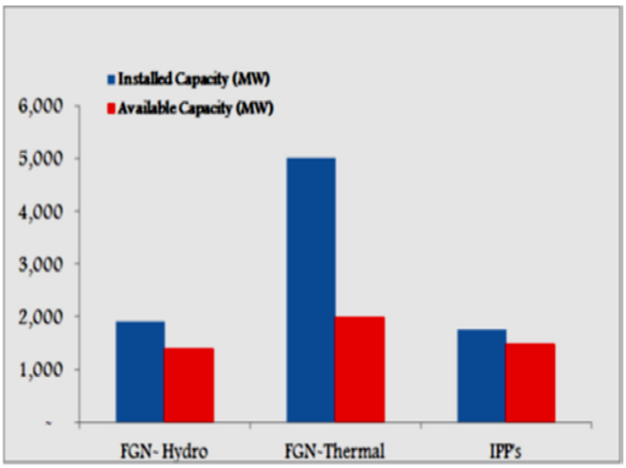

Fig. 2. Comparison of Installed against available capacity of power generation by type in Nigeria as of 2011. FGN stands for Federal Government of Nigeria while IPPs stands for Independent Power Producers [37].

reserves in Nigeria clearly exceed their utilization level. Table 1 shows a breakdown of the RE reserves and potentials in Nigeria. It is obvious that Nigeria has enough resources to cater for its energy need. Some of the resources are not tapped and the potential is vital for Nigeria's economic growth. However, access and utilization, which are the major drivers of the growth, are lacking [31].

On a global scale, less than 15% of primary energy supply is RE, and the major energy sources in developing countries are wood fuel and hydropower [32]; and worldwide, the latter and wind power are predicted to provide the largest share of the projected growth in total renewable generation [33].

Nigeria generates electricity at a commercial scale from four major energy sources: natural gas, oil, hydro and coal. Fig. 1 presents the percentage contributions of each of the sources. Since coal is neglected, petroleum (oil and gas) has contributed over 70% of the commercial primary energy in Nigeria [8].

The over-dependence of the Nigerian energy sector on petroleum has slowed down the development of alternative fuels. In order to achieve the Vision 20:2020, efforts must be made toward achieving a diversified energy supply mix, which will ensure greater energy security for Nigeria.

2.1. Nigeria's electricity power sector outlook

The Nigeria Electricity Supply Company (NESCO) commenced operations in 1929; in the attempt to connect all parts of the country to the national grid and ensure secured electricity supply, NESCO has undergone so many transformations and reforms. It was renamed National Electric Power Authority (NEPA) in 1972. NEPA was known to have a burden of subsidies, low service quality and woeful collection of tariff. The reform act of 2005 unbundled NEPA into 18 companies (under the flag of Power holding Company of Nigeria): 6 generating companies, 1 transmission company and 11 distribution companies. The generating companies are made of 3 hydro and 9 thermal (gas based) stations with their output shown in Table 2 [34]. The total

Table 3
Current and future electricity mix in Nigeria [1,38].

Technology type	Capacity (MW) 2003	Additional capacity (MW) 2010	Additional capacity (MW) 2020	Additional capacity (MW) 2030
Hydro	1920	n/a	4740	5748
Biomass	n/a	n/a	5	5
Wind	n/a	n/a	20	20
Solar PV	n/a	n/a	75	425
Solar Thermal	n/a	n/a	1	20
Total addition		7289	8280	12,858
Cumulative total	6472	13,761	20,276	29,394

installed and available power generation capacities in Nigeria is depicted in Fig. 2.

2.2. Nigeria's electricity expansion plan

The FGN power expansion plans indicate that the power sector will undergo significant changes within the short to medium time. From the FGN's proposal (see Table 3), the generation capacity of the grid is set to increase by almost four times the installed capacity by 2030 with the IPPs expected to play vital roles in the plan [38].

In its desperate attempt to address the energy poverty, the government of Nigeria may consider solely the further development of conventional electricity technologies (like coal, oil and gas) that are readily available in Nigeria with little or no concern on the environmental impact of these technologies. As the world is moving towards an agreement that would charge power plants for CO_2 emission (due to the increasing threat of global warming), the days of cheap electricity from the conventional technologies will be gone if emission charges are included [39]. The situation of the electricity consumers in Nigeria is disturbing such that the environmental issues may not be for now of significance among the public. Nigeria's CO_2 emission was estimated to be 36.9 million tons in 1985, and on the assumption that no gas was flared in 2025, this figure was estimated to rise to about 73.6 million tons [40]. This is an indication that the country has to consider clean technologies in curtailing its energy crisis.

Hydrofuel will maintain its position as a main driver of the electricity sector in the short and medium terms. Renewable fuels like solar, biomass and wind are expected to play roles in sustaining the Vision 20:2020; though their full potentials are not going to be taped. This shows that the economy of Nigeria will be reliant on its fossil fuel reserve for a long period of time. The generation capacity is predicted to grow from 6.9 in the base year to over 25 GW.

The current (2010) and future (up to 2030) (Fig. 3) energy mix shows the government's plan to diversify the country's energy mix by expanding the fuel types, which include oil, gas, coal, nuclear, wind and solar. This will reduce the overdependence of the power sector on petroleum, which has slowed down the development of other fuels that are available in Nigeria. The hydropower capacity is expected to increase from 1300 MW in the base year to about 5800 MW in the end year. The capacity of the gas (thermal) plant will increase from 5600 MW to 13,600 MW by 2030. The country's coal capacity is expected to change from almost nil to 1300 MW by 2013. Nuclear energy is expected to generate 1000 MW by 2022 and the capacity is

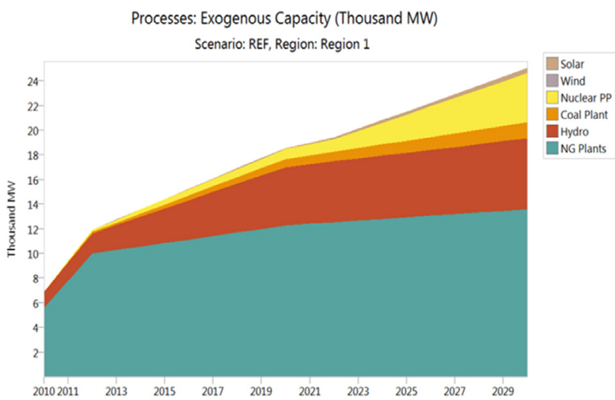

Fig. 3. Current and future committed capacity of Nigeria to achieve and sustain the Vision 20:2020 [41].

Table 4
Commissioned large hydropower stations in Nigeria.

Location	Capacity (MW)	Commissioned date	River
Shiroro	600	1990	Kaduna
Kainji	760	1968	Niger
Jebba	570	1984	Niger
Zamfara	100	2012	Bunsuru

Table 5
Planned large hydropower stations in Nigeria. Data source: [44].

Location	Capacity (MW)
Ikom	730
Lokoja	1050
Zungeru	450
Mambilla hydro	3960
Makurdi hydro	1062
Onitsha hydro	1050
Gurara (Abuja hydro)	300

expected to grow by threefold of the base year value in 2030. Solar capacity is expected to increase from 75 MW by 2020 to 475 MW by 2030 [41].

The current energy policy is critical to tackling carbon emission, which causes climate change and emphasizes the government's willingness to pursue nuclear energy in full capacity [42]. The policy deemphasizes the use of fuel wood as part of the country's energy mix, as it encourages deforestation and contributes heavily to the country's high CO_2 emission.

The environmental consequences of installing and operating an energy facility are enormous, as the facilities may lead to disruption of the ecosystem. On the other hand, any expansion on Nigeria's grid will reduce the use of private generators, which tend to be more environmental damaging as well as sources for noise pollution; diesel-fueled generators emit a complex mixture of air pollutants, which are responsible for chronic respiratory diseases and lung cancer in non-smokers [41,43].

3. Status of renewable energy in Nigeria

Here we present and discuss the current status of major RE technologies for power generation in Nigeria.

3.1. Hydropower

As earlier mentioned, Large Hydro Power (LHP) is contributing over 30% to the present total installed generation capacity in Nigeria. This makes it one of the major sources of electricity generation in the country. The main reason for this is the availability of many large rivers in the country, some of which are yet to be tapped. The commissioned and planned LHP stations in Nigeria are shown in Tables 4 and 5 respectively. A successful execution of the planned LHP projects and proper maintenance of the already commissioned LHP projects will lead to LHP providing more than double the amount of the present available generation capacity in the country. This clearly indicates the role LHP can play in alleviating the present electricity crisis in the country. A high penetration of LHP into the generation capacity in the country will lead to reduction in environment pollution that is associated with fossil-based electricity.

Unlike the LHP scheme that is based on the availability of large rivers, SHP makes use of small rivers, streams, waterfalls or storage dams to generate electric power. SHP is defined in Nigeria as hydropower station capable of generating up to 10 MW capacity. Plants with capacities up to 1 MW are considered mini-hydro-power, while those with capacity up to 500 kW are considered as micro-hydropower [45]. Considering the availability of SHP generation sources in different parts of the country, the SHP potentials in Nigeria are very huge. UNIDO Regional Centre on SHP reported that the gross SHP potential (for plants up to 10 MW) is 720 MW, the technically feasible potential is 605 MW and the economically feasible potential is 498.4 MW [45].

Many potential sites for electricity generation using SHP have also been identified across the country as summarized in Table 4 and others are still being investigated. These potentials can be economically tapped for the development of electric power generation for remote, off-grid and grid connected consumers [29]. The total electricity generation capacity from SHP is estimated to be in the region of 3500 WM [46]. This is well above the present total available generation capacity for the whole country that fluctuates around 2500 MW. With this, SHP is set to be a major contributor to electric generation capacity in the country. Some rural electrification projects (Table 6) using SHP are already available, while others are in the process of being developed [10]. A continuous effort to develop the identified potentials will go a long way in providing electrificity to the rural communities as well as help in overcoming the electricity crisis in the country. The effort needs to include the development strategy to overcome the challenges facing the SHP development in the country. The challenges, which are also relevant to other RESs include huge upfront financial investment, lack of skilled manpower and local manufacturing capacity, security concern for foreign investors and poor revenue collection culture.

3.2. Solar energy

Solar energy is harnessed through the conversion of sunlight into electricity through the use of solar cells in solar panel. This system is called Photovoltaic (PV) system [49].

Nigeria with her location close to the equator has high potential for the development of full scale solar energy driven economy. Nigeria is located within a region where sunshine is evenly distributed throughout the year [15]. The country's annual daily average of total solar radiation has been estimated to be 12.6 MJ/m^2/day (equivalent of 3.5 kWh/m^2/day) in the coastal region and 25.2 MJ/m^2/day (7.0 kWh/m^2/day) in the far north. Based on these figures, an average of 6,372,613 PJ/year (E1770 thousand TWh/year) of solar energy is estimated to fall on the entire land area of Nigeria [15,50]. One of the advantages of solar energy in Nigeria's energy sector is that it

Table 6
Summary of SHP potential sites in Nigeria. Data source [47,48].

S/No	State	Potential sites	Total estimate generation (MW)
1	Adamawa	3	28.6
2	Akwa Ibom	13	
3	Bauchi	1	0.15
4	Benue	10	13.06
5	Cross River	3	3
6	Delta	1	1
7	Ebony	5	3
8	Edo	5	3.83
9	Ekiti	6	1.25
10	Enugu	1	
11	FCT	6	
12	Gombe	2	35.099
13	Imo	71	
14	Kaduna	15	25
15	Kano	2	14
16	Katsina	11	234.34
17	Kebbi	1	
18	Kogi	2	1.05
19	Kwara	4	5.2
20	Nassarawa	3	0.45
21	Niger	11	110.58
22	Ogun	13	15.61
23	Ondo	1	1.3
24	Osun	8	2.62
25	Oyo	3	1.06
26	Plateau	14	89.1
27	Sokoto	1	
28	Taraba	9	134.72
29	Yobe	5	
30	Zamfara	16	
	Total	246	724.019

could be used for providing electricity to small settlements that are not connected to the national energy grid; other applications of solar that could be expanded in Nigeria are water pumping, traffic lighting, rural clinic and primary schools lightening [41].

Among the most needed amenities to be provided in rural settlements are small health care facilities. And some of the equipments that are needed for storage of vaccines and medical supplies are refrigerators which could be substituted with a portable solar refrigerator [26].

Fig. 4 is a zone based map of solar radiation intensity in Nigeria. Zone I comprises of states in the north-eastern Nigeria, which receive solar radiation intensity in the range of 5500–6500 Wh m^{-2}. Zone II comprises of the states in north-west and north-central Nigeria, where the average solar intensity ranges from 4500 to 5500 Wh m^{-2}. Zone III constitutes states from the south-west, south-east and south–south regions; the average solar radiation intensity in this region ranges from 4000 to 4500 Wh m^{-2}.

Fagbenle [51] estimated the total radiation in Nigeria using meteorological data obtained from the country's meteorological agency (NIMET); the study showed that there is correlation between increase in solar radiation and the increase in latitude and irrespective of the zone, the least total solar radiation intensity is witnessed in the month of August. A follow up study which requires the inclusion of the most recent metrological data is recommended to justify the assertion. This is due to the recent changes in global climate that are linked with fossil fuel combustion. The impacts of climate change are manifesting on Nigeria and its neighboring countries [52]. Ref. [52] compared simulated solar irradiance with observed data obtained from NIMET and NASSA. The result of [52] confirmed the assertion by showing that the minimum values of solar irradiance were observed at the end of the wet season in August across the zones for both model and the observations.

The current capacity of solar electricity in Nigeria is estimated at less than 1 MW, which is relatively small. It is estimated that the

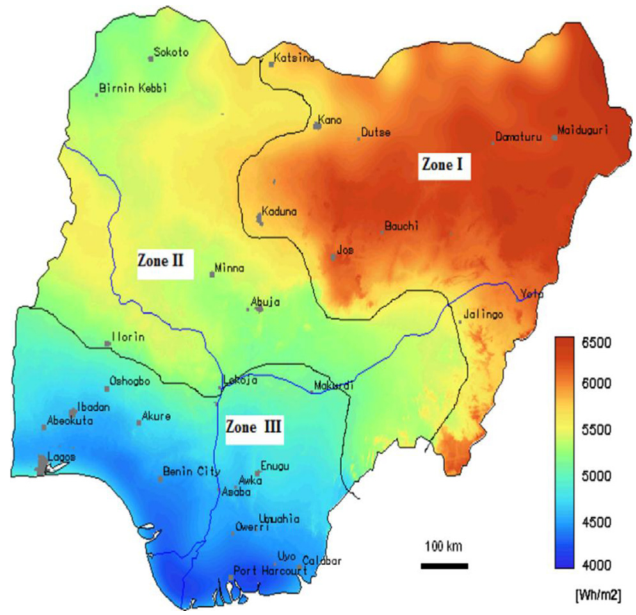

Fig. 4. Zone based solar radiation map of Nigeria [53].

supply capacity of solar will increase to 1 MW by 2020 and 20 MW by 2030 [41]. Fagbenle [54] looked into the prospects of solarization of transport sector in Nigeria. Some of the factors that have been noted by Ref. [54] to underpin the development of large scale solar projects (such as transport system) in Nigeria are: lack of technical skills to manufacture PV cells locally and the lack of modules and arrays to achieve large scale projects. A recent study by Dada [10] has argued that the integration of Smart/Micro-Grid would play an important role in overcoming the challenges of RE resources in Nigeria as small power producers like owners of roof top solar panels and wind farms through the use of intelligent systems will be connected to supply the country's grid system.

Due to the fact that Nigeria is located in a region that favors the development of solar energy technology, a suggestion has been made for a systematic and harmonized financial investment in the area of solar energy research to reduce the country's over dependence on its depleting fossil reserve [26]. Some of the major issues that need to be addressed are the market competiveness of solar as it is at present 20 times higher in cost than the conventional fuels which are readily available. Before the potential of solar energy can be tapped in Nigeria, both government and private sectors have to play some major roles in ensuring that there are working policies and guidelines in that respect. In the current authors' opinion, a low interest rate loan should be offered to members of the public who are willing to use solar panels in their homes, small-scale businesses and farms. In Malaysia for instance, a study on the way forward for PV in the country by Muhammad-Sukki, Munir [55] has found that for home owners, a soft loan facility with an interest rate of 5% is a viable way of funding private solar programs. This could be emulated in Nigeria under stringent government regulation.

The lack of intensive private sector involvement and the Federal Government's role as a sole financier of the electricity sector in Nigeria have been noted to be some of the factors that have stalled the full scale development of RE and other energy technologies in Nigeria [41]. However, the recent policy that allows the State governments to generate and sell electricity within their domain could lead to further development of solar and other RE resources like SHP and wind in the country. As at January 2014, there were over 60 solar projects in Nigeria [15] and it is estimated that this number is expected to increase in the future.

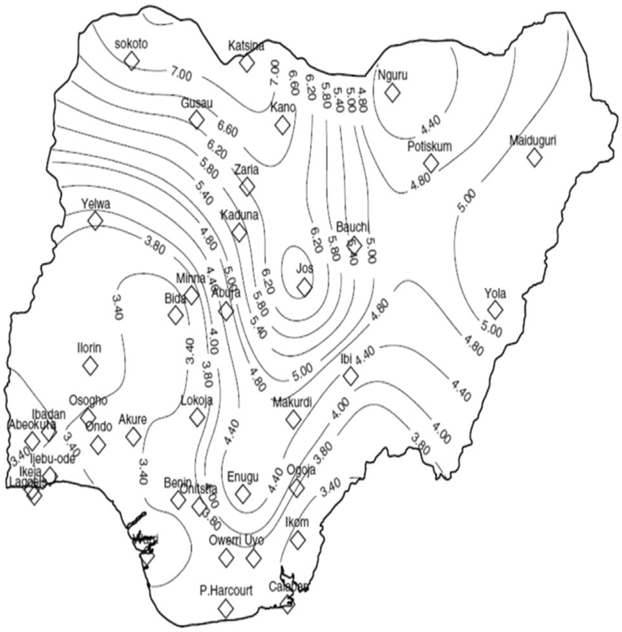

Fig. 5. Isovents of average wind speeds in m/s based on 40 year's measurements (1968–2007) at 10 m height [62,64].

3.3. Wind energy

Wind turbines convert the kinetic energy of the wind to electrical energy by rotating the blades [56]. Wind is a natural resource that is free and available both day and night. The technical potential of the world onshore wind energy is very large—$20{,}000 \times 10^9$–$50{,}000 \times 10^9$ kWh per year against the current total annual world electricity consumption of about $15{,}000 \times 10^9$ kWh [56]. In determining the viability of wind as an energy source, it is important to know the greatest extent possible of the wind resources before investing in and installing a wind turbine [57].

Wind economic potential depends upon factors like average wind speed, statistical wind speed distribution, turbulence intensities and the cost of wind turbine systems [56]. To this end many researchers have investigated the wind energy potentials in different parts of Nigeria to determine its viability for power generation. Fagbenle and colleagues [58] carried out the assessment of wind energy potential in two sites in North-East Nigeria using 21 years' monthly mean wind data at 10 m height. They concluded that both sites are suitable for standalone and medium scale wind power generation. Ohunakin [59] investigated the wind characteristics of five sites in North-East Nigeria using 37-year monthly wind data at a height of 10 m. The results showed that wind speeds range from 3.18 to 7.04 m/s. Similar studies by the same author showed that the North-West and North-East geopolitical regions have a mean wind speeds above 4.8 m/s [60] and annual mean wind speeds that range from 2.747 m/s to 4.570 m/s for North-Central region [61].

Nationally, the annual wind speed at 10 m above the ground varied from 2.3 to 3.4 m/s for sites along the coastal areas and 3.0 – 3.9 m/s for high land areas and semi-arid regions with peak wind speed occurring between April and August for most sites [62,17,63]. Fig. 5 depicts the isovents of the average wind speed data from the whole forty-four wind stations in m/s. The data is based on NIMET 40 year's measurements (1968–2007) of wind speeds at 10 m height from NIMET. This shows Nigeria has good wind resources over most parts of the country [62].

Although there is vast research on the potentials of wind power in Nigeria, its development has not attracted attention [65]. Unlike developed and emerging countries, such as Germany, USA, UK and China that are actively promoting and developing the wind energy for electricity generation, the utilization level of wind energy in Nigeria is still relatively low. The only notable wind power generation in Nigeria is the first Nigeria wind farm (37 wind turbines) in Rimi village (Katsina state). This has a total generation capacity of 10 MW and is expected to be commissioned soon [66]. The project is part of the FGN's agenda to increase the contribution of RE to electricity generation capacity in the country. Other wind based power generations are the 5 KW in Sayya Gidan-Gada (Sokato state), 0.75 KW in Dan-Jawa village (Sokoto state), 1KW at Benin energy research centre (Edo state) and rehabilitated windmill for water pumping at Kadawa village (Kano state). Many other windmills used for water pumping installed in the 1950s and 1960s in the Northern part of Nigeria are no longer functioning [67].

The low level penetration of wind energy into the energy mix in Nigeria can be attributed to many factors, such as low financing, lack of awareness and encouragement to embrace wind technologies and technical capacities [68]. All these need to be addressed through appropriate policies and legislations in order to fully utilize wind energy potentials for electricity generation in the country. Other areas of wind application are in electricity generation for the remote communities, small-scale windmill for water pumping and utility-scale wind power generation integrated into the electricity grid. The most attractive sites for utility-scale wind power generation are the coastal areas, the offshore states mentioned above, the inland hilly regions of the North, the mountainous terrains in the middle belt and the northern part of the country [69]. Exploration of these potentials will help in the diversification of Nigeria's energy mix, boost electricity generation to cope with electricity demand, create employment for youths and contribute to the reduction of carbon footprint.

3.4. Biomass/bioenergy

Biomass refers to any living matter; including plants, algae, micro-organisms and animals. They are compounds of carbon, oxygen, nitrogen and sulfur, with significant amounts of free energy in the form of chemical bonds [70,71]. The energy can be released on breaking the molecule to generate heat, which can be converted to mechanical work or electricity. Biomass can also be used as a raw material for transport fuel if it is transformed into a liquid form. In principle, both food and non-food biomass can be used to produce fuels commonly referred to as biofuels [71], which can either be solid, gas or in liquid form.

Solid biofuel encompasses the burning of wood for domestic and industrial uses [72–74]. Biogas, such as methane, carbon dioxide, monoxide, and hydrogen is produced from microbes [75,76]. Another form of solid biofuel is wood gas that is produced from chemical cracking of wood. Large and heavy tanks are required for storage of gas hence it is not desirable as a transport fuel. Its major application is for domestic purposes. Liquid fuels are more attractive due to high energy densities and can be stored in light-weight tanks [77].

It is expected that the global biofuel production and usage should provide solutions to environmental problems including sustainability, climate change, and biodegradability among others [78]. The production and use of biofuel is not new; in 1900 Dr Rudolf Diesel's engine was fueled with peanut oil [79]. The global acceptance of biofuels showed a great increase in the past as a result of their benefits to the environment. More recently, the public acceptance decreased again due to the public concerns that gave rise to 'food versus fuel' debate [80,81].

The biomass resources available in Nigeria are wood, forage grasses and shrubs and livestock manure etc. [65,82–84]. Another source of bioenergy that is available in Nigeria is animal waste. It is estimated that Nigeria generates about 227,500 t of fresh animal waste daily; and since 1 kg of fresh animal waste produces about

0.03 m^3 biogas, Nigeria has the ability to potentially produce about 6.8 million m^3 of biogas per day from the generated animal waste only [46]. Over 80% of Nigerians depend on fuel wood for cooking and heating and the current energy policy of Nigeria has deemphasized the use of fuel wood for energy. The potential of bioenergy resources in Nigeria for bioelectric power generation and the role of bioenergy in curtailing the country's electricity crisis are promising [16].

The idea of bioenergy may not be welcomed in Nigeria especially when food crops are involved. However, it is noted in Ref. [85] that concept of biofuel which would result in immediate benefits to Nigeria, is the production of biogas waste, which does not require irrigation or land usage and also has the potential to make the environment cleaner. The production of biogas from waste would result in a decrease in use of firewood for energy in Nigeria.

Globally, some of the factors affecting the production of biofuels include the feedstock usage, availability as well as inefficient production strategies [86]. High cost of enzymes that are required for large scale feedstock processing which make the production expensive affect the biofuel industry [87–90]. However, in the case of Nigeria, the materials that are needed for biofuel and biogas production are readily available but the technical skill and infrastructures for large scale bioenergy production are lacking.

The results of a number of experimental studies on biofuels and biogas production in Nigeria have been published in the literature, for instance, biogas from organic waste by Ref. [91], ethanol production from agricultural residue by Ref. [92], biofuels production from cocoa pods and plantain peels by Ref. [93], biogenic waste methane emissions and methane optimization by Ref. [94].

4. Government policies and legislations on renewable energy

It is very clear from the current status of RE in Nigeria that the application of RE technologies for electric power generation in Nigeria has been slow. New measures to boost the growth of RE in the country are needed. These measures will come in form of policies, regulations, legislative framework, licensing arrangements for private-sector operators, Feed-in Tariffs and clarifying market rules for RE services and products [46]. Here we discuss some policies, regulations and legislation frameworks that can speed up the development of RE for power generation in Nigeria.

4.1. Power sector reforms and regulations

The enactment of the Electricity Power Sector Reform Act (EPSA) of 2005 by the Federal Government marks the end of vertically integrated electric utility in Nigeria. The Act stipulates the unbundling and privatization of electricity sector thereby allowing IPPs to generate and sell to the national grid. The general aims of the reforms in Nigeria like deregulated electricity industries in other countries across the globe are to improve efficiency, to create a more competitive energy-producing industry, to attract new – outside – investors and also to divest the state of over-regulated, and often heavily indebted, electricity undertaking, providing welcome cash for the government that can be spent on social services [95–97]. EPSA established the National Electricity Regulatory Commission (NERC) to coordinate the activities of the deregulated electricity market. Rural Electricity Agency (REA) was also established with the statutory functions of promoting, supporting and providing electricity access to rural and semi-urban areas of the country. REA is responsible for administration of the Rural Electrification Fund (REF), which provides autonomous funding opportunity through the Renewable Electricity Trust Fund (RETF) [98]. Private individuals are also allowed to own and operate off-grid power generator with a capacity of less than 1 MW without acquiring electricity license from NERC and regardless of the fuel type [65].

Recently, NERC signed two regulations – the Independent Electricity Distribution Network (IEDN) and Embedded Generation 2012. The regulation on embedded generation permits investors, communities, state and local governments to generate and distribute electricity for their exclusive consumption using facilities of existing electricity distribution companies or independent electricity distribution network operators, while the regulation on independent electricity distribution networks permits communities, local and state governments to invest in electricity distribution networks in areas without access to the grid or distribution network or areas poorly serviced [99]. The regulations along with EPSA will positively impact investments in RE power generation in Nigeria, especially in the remote communities where the cost of grid extension is extremely high.

4.2. National energy policy and renewable master plan

The Nigeria government approved the National Energy Policy (NEP) in 2003 with main focus on the viable energy sources for sustainable national development. RE is one of the energy types articulated in the policy [100]. The objectives of the NEP are detailed in Refs. [101,100]. The Renewable Energy Master Plan (REMP) developed in 2005 and lunched in 2006 aims to promote the use of RE, boost energy diversification, and help to reduce carbon footprints. To achieve this, REMP set a map to increase the share of RE in the national energy supply mix through three development stages: short term, medium term and long term [102]. The target set for the three development stages is shown in Table 7. The development of REMP and the growing demand for increased penetration of RESs into the Nigeria electricity supply mix [103,104] are attributable to the availability of abundant and diverse renewable energy sources (RESs) in Nigeria as highlighted in previous sections.

4.3. Other relevant policies and regulations

Energizing Access to Sustainable Energy (EASE) program aims to improve the enabling framework conditions for renewable energy and energy efficiency in Nigeria. It focuses on the use of renewable energies by Small and Medium Enterprises (SMEs) and households and aims to address the massive deforestation and cutting of trees for fuel wood, which is the main energy source for the majority of the population, by planting more trees. EASE program will also contribute to resource conservation and help fight CO2 emissions. The program is in partnership with the World Bank and the GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) [46].

The Nigerian biofuels policy and incentives drafted in 2007 by the Nigerian National Petroleum Corporation (NNPC) aims to integrate agricultural activities with oil and gas exploration and production. The policy targets to address the key government plans with regard to ethanol and biodiesel production across the country. A detailed description of objective, anticipated benefits and investment incentives can be found in Ref. [105].

4.4. Summary

The above described policies and regulations are still short of market-oriented policies that can drive the increased RE investors' participation in constructive development of the available RE resources in Nigeria. Incentives through effective policy making is absolutely necessary to strengthen the prospect for investment and development of RE technologies in the country [65]. A major problem confronting the RE in the country is the high upfront installation cost, which is beyond the reach of a large percentage of Nigerian population. The only solution is to encourage the private sector to drive the

Table 7
Target for renewable energy contribution to electricity generation in Nigeria [100].

Renewable energy sources	Short—2015 (MW)	Medium—2020 (MW)	Long—2030 (MW)
Large hydro power (LHP)	4000	9000	11,250
Small hydro power	100	760	3500
Solar photovoltaic	300	4000	30,005
Solar thermal	200	2136	18,127
Biomass	5	30	100
Wind	23	40	50
All renewable sources	4728	15,966	63,032
All energy sources	47,490	88,698	315,158
% of Renewable sources	10%	18%	20%
% Renewable minus LHP	1.3%	8%	16%

development of RE. This can be done through incentive-oriented-policies, such as Feed-in tariffs [106] as in many European Member States and elsewhere [107,108], tax rebate, subsides and zero import duty on RE equipment, access to affordable loan and investment in research and development in areas of RE power generation systems and its integration into the electricity grid.

5. RE development in sub-Sahara African countries

This section will present an overview of RE development in some African countries and compare their efforts with that of Nigeria. The countries considered are South Africa, Ghana, Cameroon and Senegal.

5.1. RE in South Africa

South Africa has the most ambitious renewable energy aspirations among all countries in the continent. The 1998 Energy Policy of South Africa states that the country will acquire 15% of its national supply from RE [109]. Going by this, South Africa's RE supply should be about 15% or more than that at present. The question is has the county achieved this target? An analysis of the energy mix in South Africa by Ref. [110] has shown that as in 2008, coal contributed 86%, nuclear contributed 5% of the country's energy mix. Other sources are hydro and gas which combined to contribute 9% of the energy mix. Pegels [110] noted that in spite of a high RE resource potential, there has so far been little growth in the deployment of renewables in South Africa. The two major factors that have been identified to stall the RE development in South Africa are the country's energy innovation system and the economics of renewable energy technologies [110]. The research on energy in the country has been argued to be centered on fossil resources, which is a tradition inherited from the apartheid regime. In Nigeria for instance, the tradition has been that the FGN is a sole financier of the electricity sector. This was inherited from the military regimes.

Large industrialization and the extensive dependence of the South Africa's electricity sector (with installed capacity of 42,000 MW) on fossil fuel have resulted in enormous greenhouse gases emission. One of the most promising RE resources in South Africa is solar, another RE resource that could be used to power the country's economy is wind which has an estimated supply potential of 184 TWh [111]. The government of South Africa has introduced several policies to support RE in the country. One of such policies is the feed-in tariff. The renewable energy feed-in tariff was launched in 2009. It requires the national electricity utility Eskom, to purchase renewable energy from qualifying generators at predetermined prices [111–113]. These predetermined prices act as an incentive to renewable energy developers and private investors by reducing financial risk and providing market certainty [114]. In order to achieve the goal of 15% RE in South Africa, private investors need to play a vital role as highlighted by [112]. The private companies in South Africa do not have to wait for government to drive the process towards achieving the Integrated Resource Plan. The private investor could bring about their own plans that would benefit them financially [112]. The involvement of private investors in RE deployment in both South Africa and Nigeria will serve as major driver towards achieving an RE driven economy in the countries.

5.2. RE in Cameroon

The situation in Cameroon is similar to that of Nigeria in the case when one looks at things from the angle of population dependence on fuelwood for energy. The environmental consequence of excessive exploitation of firewood is prevalent [115]. Studies by the World Bank estimate urban electricity accessibility at between 45% and 50% in Cameroon. However, the national averages are generally very low [116,117]. It is estimated that only 15% and 5% of the urban and rural populations, respectively have access to electricity in Cameroon [115,118].

The theoretical estimate of solar energy potential in Cameroon ranges from 4 to 5.8 kWh/day/m^2 [115,119,120]. The wind speed ranges from 2.8 to 4.1 m/s in the north and 1.2–1.8 m/s in the southern part of the country [115,121,122]. The hydropotential in Cameroon is estimated at 115 TWh/year and this makes the country the second largest hydropotential in Africa after Democratic Republic of Congo [123]. Other RE resources available in Cameroon are biomass, geothermal and tidal [115,124,125].

Despite this huge RE potential in Cameroon, the absence of clear renewable energy policy in the mix and lack of enthusiasm from the government are major factors that have stalled the deployment of RE in the country; and these need to be addressed by the government and policy makers [124,126].

Compared with Nigeria, the RE development in Cameroon is slow since it has been argued by Ref. [124] that there is no clear government policy on RE. Nigeria has these policies on documents, but the implementation of government policies in Nigeria is a major challenge.

5.3. RE in Ghana

Ghana's Renewable Energy Development Program [127] aimed to assess the availability of renewable energy resources and to examine the technical feasibility and cost-effectiveness of RE technologies in the country among other goals. The program [127] highlighted and discussed the RE potential of Ghana grouping them into two major groups; biomass and solar. Ref. [127] identified major RE projects in the country and suggested how they could be improved. Ghana has been argued to achieve commendable access to modern energy services compared to her sub-Saharan peers [128]. Increases in industrialization and urbanization have resulted in high energy intensity in Ghana. To reduce the energy intensity, Ref. [129] suggested that policies aimed at encouraging the production of less energy intensive products and implementation of high energy efficient technologies in the manufacturing sector should be promoted. Ghana's renewable energy resources could be harnessed to play a role in supplying both rural and urban households.

There are huge biomass resources in Ghana that have the potential for use as feedstock for biogas production to reduce the country's over dependence on fuelwood and fossil resources [130]. Ref. [130] assessed the potential of biogas in Ghana and concluded that the country has potential of constructing about

278,000 biogas plants; and as of 2011, only about 100 biogas plants have so far been constructed. In 2008, fuelwood contributed 72% of primary energy supply in Ghana while the percentage contributions of hydro and crude oil were only 6% and 22% respectively [130,131]. This demonstrates the nation's over reliance on fuelwood for charcoal and firewood as it is the case in other sub-Saharan African countries like Cameroon and Nigeria.

In sub-Saharan African countries, the deployment of biogas technology has been relatively unsuccessful [130]. This is attributed to failure of governments to support biogas technology through a dedicated energy policy, poor design and construction of digesters, wrong operation and lack of maintenance by users [130]. Other factors that have been identified to slow down the deployment of the technology are nonexistence of project monitoring and follow ups by promoters, and poor ownership responsibility by users [130,132]. Another standalone factor that has been slowing the technology is its economy. For instance, in 2009, the average investment cost of a 10 m^3 biogas plant ranged from \$2800 to \$4200. These figures are far above the financial capability of a rural farmer or a nomadic cattle famer [132]. Ref.[130] concluded that intensive public education program and well developed institutional framework are required for the successful deployment of biogas technology in Ghana. We argue that this should also be applicable in other sub-Saharan African countries like Cameroon, Senegal and Nigeria.

5.4. RE in Senegal

Like Nigeria, Senegal is facing energy crisis with majority of the rural population living without access to electricity. Despite large-scale potential of RESs for electricity generation in the country, nearly 85% of rural population has no access to electricity [133,134]. As argued in Ref. [135], the energy crises could be curtailed if RE is used as a primary source of energy in rural areas. Senegal has good potential to generate on-grid and off-grid electricity using solar, wind, hydro and biomass. RE potential in Senegal has been demonstrated in several studies. The solar irradiation is estimated to be above 2000 kWh/m^2/year for global horizontal irradiation and above 1800 kWh/m^2/year for direct normal irradiation [136]. The wind power potential is concentrated along the coast with observable wind speed of 3.7–6.1 m/s in the 50 km-long coastal strip between Dakar and St. Louis [136,137]. The hydroelectric potential of Senegal and Gambia rivers is estimated at 1400 MW. Solid biomass and liquid biofuels also have potential in Senegal [138]. Biomass dominates the energy source with a contribution of over 50% of the national energy balance [138]. Agricultural and agribusiness by-products are abundant with very good potential for on-grid and off-grid electricity generation, while plant species such as plant oil, jatropha-curcas, cattails, sunflower, cotton, castor, sweet sorghum etc. are expected to play a significant role in biofuel production in Senegal [133,136,139–141].

Senegal is far ahead of Nigeria in the promotion of RE development in the rural areas. Since 2008 the new Energy Sector Development Policy Paper has been in place with a clear direction for RE [138]. The policy sets a penetration rate for renewable sources of energy and biofuels of at least 15% of internal energy consumption by 2020 [137]. The commitment to institutional reform and policy has positioned Senegal as a leader in RE promotion in the Economic Commission of Western Africa (ECOWAS) region leading to the country being tasked to develop solar energy projects in the sub-region by Heads of State and Government in the ECOWAS Summit held in July 2010, and subsequently chosen as one of the pilot countries to field-test the methodology being developed by International Renewable Energy Agency (IRENA) for the renewables readiness assessment [138].

6. Conclusions

The unabated electricity crisis and the need to reduce the greenhouse gases should be the major drivers for the pursuing RE options in the Nigeria. This work presented the current status of the major RE technologies in Nigeria to help advance the course of RE for power generation. The potentials of RE in the country, planned and existing RE projects are reviewed. Relevant policies and legislations are highlighted, and suggestions for market-oriented policies were discussed. The paper also presented an overview of RE development in sub-Sahara Africa by discussing the status of RE in South Africa, Cameroon, Ghana and Senegal.

The importance of RE to Nigeria energy mix is very clear and well recognized. The large body of research works on RE shows that nearly all parts of the country have the potentials for electricity generation using at least two forms of RE technologies. Despite this, the RE development in Nigeria is very slow compared with the developed and emerging countries. Wind power use for electricity generation is still relatively small. However, the experience gained from the installation and commissioning of Nigeria's first wind farms is expected to encourage further investment in the wind power technology in Nigeria. Solar power products are booming in current energy market worldwide [142]. The installed capacity of the solar power plants in Nigeria would be boosted if policy on feed-in-tariffs is put in place. The electricity grid must however be made ready for RE integration using available technologies as discussed in Ref. [10]. The support for the SHP development in the country through United Nations Industrial Development Organization (UNIDO) – Regional Centre for SHP in Africa is encouraging and should be intensified.

The potentials of RE for power generation are there but more efforts to enhance RE utilization in the country are needed. Private partnership agreement, investment in research and development, government incentives through appropriate policies and regulations backed by legislations are the way forward to promote and support the use of RE in Nigeria. New market-oriented policies and legislations are needed to enhance incentives for the development of RE. This can be done through a variety of methods, including the acquisition mechanisms, incentives for demonstration projects, and the loosening of regulatory restrictions [142]. Appropriate market-driven policies will lead to a significant growth in RE development and utilization in the country. The RE for both on-grid and off-grid electricity generation needs to be continuously promoted and encouraged through the strengthening of research and development capability, training of manpower, operation and maintenance culture and local manufacturing of RE equipment. An integrated power solution based on the current centralized power systems and decentralized electricity generation using RE technologies needs to be rigorously pursued in order to overcome the present electricity crisis, thereby moving the country towards economic prosperity.

The suggested methods for promoting the utilization of RE in Nigeria are equally applicable to other sub-Sahara African countries. The major factors militating against the RE deployment in most of these countries are lack of government clear policies on RE and the economy of RE technologies.

Acknowledgments

A.S. Aliyu wishes to acknowledge the support of the Research Management Center of Universiti Teknologi Malaysia for its support through the Post Doc fellowship scheme, project number (Q.J130000.21A2.01E98) under Prof. Ahmad Termizi Ramli. JO Dada would like to thank his former line manager (Pedro Mendes) and University of Manchester for the provision of resources used for his own contribution in this work.

References

[1] Obadote D. Energy Crisis in Nigeria: technical issues and solutions. Power Sector Prayer Conference June 2009.
[2] Sambo AS, Garba B, Zarma IH, Gaji MM. Electricity generation and the present challenges in the Nigerian power sector. J Energy Power Eng 2012;6:1050–9.
[3] InternetWorldStatistics I. Population of Nigeria. InternetWorldStatistics 2011.
[4] Iwayemi A. Nigeria's dual energy problems: policy issues and challenges. Int Assoc Energy Econ 2008:17–21.
[5] Okafor E, Joe-Uzuegbu C. Challenges to development of renewable energy for electric power sector in Nigeria. Int J Acad Res 2010;2:211–6.
[6] ECN ECoN. FG to incur N177bn in electricity subsidy – NERC. 2011.
[7] Ojo E. Manufacturers need 2,000 MW of Electricity to Stay Afloat-MAN. BusinessDay Nigeria. Lagos: BusinessDay Nigeria; 2009.
[8] Kennedy-Darling J, Hoyt N, Murao K, Ross A. The Energy Crisis of Nigeria: An Overview and Implications for the Future. Chicago: The University of Chicago; 2008.
[9] Sambo A. Alternative generation and renewable energy. 2nd Power Business Leaders Summit, Ibom Gulf Resort, Akwa Ibom State 12th–14th December. 2007.
[10] Dada JO. Towards understanding the benefits and challenges of Smart/Micro-Grid for electricity supply system in Nigeria. Renew Sustain Energy Rev 2014;38:1003–14.
[11] Lawal Nadabo S. Renewable Energy as a Solution to Nigerian Energy Crisis. Vasa Yrkeshogskola: University of Applied Science; 2010.
[12] Shaaban M, Petinrin JO. Renewable energy potentials in Nigeria: meeting rural energy needs. Renew Sustain Energy Rev 2014;29:72–84.
[13] Udoakah YON, Umoh MD. Sustainably Meeting the Energy Needs of Nigeria: The Renewable Options. In: Proceedings of the IEEE International Energy Conference (ENERGYCON) 2014. pp. 326–332.
[14] Oyedepo SO. Towards achieving energy for sustainable development in Nigeria. Renew Sustain Energy Rev 2014;34:255–72.
[15] Ohunakin OS, Adaramola MS, Oyewola OM, Fagbenle RO. Solar energy applications and development in Nigeria: Drivers and barriers. Renew Sustain Energy Rev 2014;32:294–301.
[16] Mohammed YS, Mustafa MW, Bashir N, Ogundola MA, Umar U. Sustainable potential of bioenergy resources for distributed power generation development in Nigeria. Renew Sustain Energy Rev 2014;34:361–70.
[17] Adaramola MS, Oyewola OM. On wind speed pattern and energy potential in Nigeria. Energy Policy 2011;39:2501–6.
[18] Adaramola MS, Oyewola OM. Evaluating the performance of wind turbines in selected locations in Oyo state, Nigeria. Renew Energy 2011;36:3297–304.
[19] Adaramola MS, Oyewola OM, Ohunakin OS, Akinnawonu OO. Performance evaluation of wind turbines for energy generation in Niger Delta, Nigeria. Sustain Energy Technol Assess 2014;6:75–85.
[20] Adaramola MS, Paul SS, Oyedepo SO. Assessment of electricity generation and energy cost of wind energy conversion systems in north-central Nigeria. Energy Convers Manag 2011;52:3363–8.
[21] Oyedepo S, Adaramola M, Paul S. Analysis of wind speed data and wind energy potential in three selected locations in south-east Nigeria. Int J Energy Environ Eng 2012;3:1–11.
[22] Adaramola MS. Viability of grid-connected solar PV energy system in Jos, Nigeria. Int J Electrical Power Energy Syst 2014;61:64–9.
[23] Adaramola MS, Paul SS, Oyewola OM. Assessment of decentralized hybrid PV solar–diesel power system for applications in Northern part of Nigeria. Energy Sustain Dev 2014;19:72–82.
[24] Akpan US, Isihak SR, Udoakah YON. Electricity access in Nigeria: Viability of off-grid photovoltaic system. AFRICON, 20132013. pp. 1–8.
[25] Fadare DA. Modelling of solar energy potential in Nigeria using an artificial neural network model. Appl Energy 2009;86:1410–22.
[26] Okoro OI, Madueme TC. Solar energy: a necessary investment in a developing economy. Int J Sustain Energy 2006;25:23–31.
[27] Sheyin FT. Solar Energy Utilization in Agriculture in Nigeria. In: Sayigh AAM, editor. World Renewable Energy Congress VI. Oxford: Pergamon; 2000. p. 2261–5 Chapter 488.
[28] Ebhota WS, Eloka-Eboka AC, Inambao FL. Energy sustainability through domestication of energy technologies in third world countries in Africa. Industrial and Commercial Use of Energy (ICUE) 2014:1–7 International Conference on the 2014.
[29] Ohunakin OS, Ojolo SJ, Ajayi OO. Small hydropower (SHP) development in Nigeria: an assessment. Renew Sustain Energy Rev 2011;15:2006–13.
[30] Tunde AO. Small hydro schemes – taking Nigeria's energy generation to the next level. In: Proceedings of the IEEE Power Engineering Society Inaugural Conference and Exposition in Africa, 2005. p. 112–9.
[31] Oseni MO. Households' access to electricity and energy consumption pattern in Nigeria. Renew Sustain Energy Rev 2012;16:990–5.
[32] Lund H. Renewable energy strategies for sustainable development. Energy 2007;32:912–9.
[33] Vujić J, Antić DP, Vukmirović Z. Environmental impact and cost analysis of coal versus nuclear power: the US case. Energy 2012;45:31–42.
[34] Alimba JO. Cost, demand and supply and price management in the power market. Workshop on electricity economics to PHCN staff at Abuja, Nigeria 26–28 March 2010.
[35] Okoro O, Chikuni E. Power sector reforms in Nigeria: opportunities and challenges. J Energy Southern Africa 2007;18:52–7.
[36] BPE. Power generation (status and outlook); Presidential Tax Force on Power. Power Investors' Forum. Abuja 2011.
[37] Erik F. The Nigerian power sector: a case study of power sector reform and the role of PPP. 2011.
[38] Gujba H, Mulugetta Y, Azapagic A. Environmental and economic appraisal of power generation capacity expansion plan in Nigeria. Energy Policy 2010;38:5636–52.
[39] Nuttall WJ. Nuclear renaissance: technologies and policies for the future of nuclear power. New York: Taylor & Francis; 2004.
[40] Adegbulugbe AO. Energy demand and CO_2 emissions reduction options in Nigeria. Energy Policy 1991;19:940–5.
[41] Aliyu AS, Ramli AT, Saleh MA. Nigeria electricity crisis: power generation capacity expansion and environmental ramifications. Energy 2013;61:354–67.
[42] Aduba O. Nigeria to attain 4000 MW from nuclear power plants by 2030. Guardian Newspaper; 2012 18 July, 2012.
[43] Aliyu AS, Ramli AT, Saleh MA. First nuclear power in Nigeria: an attempt to address the energy crisis? Int J Nucl Gov Econ Ecol 2013;4:1–10.
[44] Zarma IH. Hydro power resources in Nigeria. 2006.
[45] Liu H, Masera, D and Esser, L. World Small Hydropower Development Report 2013. United Nations Industrial Development Organization; International Center on Small Hydro Power. 2013.
[46] (SERN) TSERN. Policy and Regulatory Overviews. 2014.
[47] Kela R, Usman KM, Tijjani A. Potentials of Small Hydro Power in Nigeria: The Current Status and Investment Opportunities. Natural gas.9, 2012, 3–17.
[48] UNIDO. Regional Centre for Small Hydro Power in Africa, 2006, Available from: ⟨http://www.unido.org/office/nigeria.html⟩.
[49] Basri NA, Ramli AT, Aliyu AS. Malaysia energy strategy towards sustainability: a panoramic overview of the benefits and challenges. Renew Sustain Energy Rev 2015;42:1094–105.
[50] E.C.N. Energy Commision of Nigeria: National Energy Policy. 2003.
[51] Fagbenle RL. Estimation of total solar radiation in Nigeria using meteorological data. Nigerian J Renew Energy 1990;1:1–10.
[52] Ohunakin OS, Adaramola MS, Oyewola OM, Fagbenle RO. Solar radiation variability in Nigeria based on multiyear RegCM3 simulations. Renew Energy. 2015;74:195–207.
[53] Huld T, Suri M, Dunlop E, Albuisson M, Wald L. Integration of Helioclim-1 database into PV-GIS to estimate solar electricity potential in Africa. In: Proceedings, 20th European Photovoltaic Solar Energy Conference. Barcelona, Spain 2005.
[54] Fagbenle R. Prospects and problems of solarizing transport technology. Nigerian J Renew Energy 1991;2:79–84.
[55] Muhammad-Sukki F, Munir AB, Ramirez-Iniguez R, Abu-Bakar SH, Mohd Yasin SH, McMeekin SG, et al. Solar photovoltaic in Malaysia: the way forward. Renew Sustain Energy Rev 2012;16:5232–44.
[56] Joselin Herbert GM, Iniyan S, Sreevalsan E, Rajapandian S. A review of wind energy technologies. Renew Sustain Energy Rev 2007;11:1117–45.
[57] Anderson E, Antkowiak M, Butt R, Davis J, Dean J, Hillesheim M, et al. A Broad Overview of Energy Efficiency and Renewable Energy Opportunities for Department of Defense Installations 2011.
[58] Fagbenle RO, Katende J, Ajayi OO, Okeniyi JO. Assessment of wind energy potential of two sites in North-East, Nigeria. Renew Energy 2011;36:1277–83.
[59] Ohunakin OS. Wind resources in North-East geopolitical zone, Nigeria: an assessment of the monthly and seasonal characteristics. Renew Sustain Energy Rev 2011;15:1977–87.
[60] Ohunakin OS. Wind resource evaluation in six selected high altitude locations in Nigeria. Renew Energy 2011;36:3273–81.
[61] Ohunakin OS. Assessment of wind energy resources for electricity generation using WECS in North-Central region, Nigeria. Renew Sustain Energy Rev 2011;15:1968–76.
[62] Ajayi OO. The Potential for Wind Energy in Nigeria. Wind Eng 2010;34:303–12.
[63] Ngala GM, Alkali B, Aji MA. Viability of wind energy as a power generation source In maiduguri, Borno state, Nigeria. Renew energy 2007;32:2242–6.
[64] Meteorological data, Oshodi. Nigeria Meteorological Agency (NIMET). 2014.
[65] Mohammed YS, Mustafa MW, Bashir N, Mokhtar AS. Renewable energy resources for distributed power generation in Nigeria: a review of the potential. Renew Sustain Energy Rev 2013;22:257–68.
[66] Salisu L, Garba I. Electricity generation using wind in Katsina State, Nigeria. Int J Eng Res Technol 2013;2.
[67] Sambo AS. Renewable energy for rural development: the Nigerian perspective. ISESCO Sci Technol Vis 2005;1:12–22.
[68] Ajayi OO. Assessment of utilization of wind energy resources in Nigeria. Energy Policy 2009;37:750–3.
[69] Saddik Amina I, Tijjani Nafiu, Alhassan Bilyaminu. Wind power: an untapped renewable energy resource in Nigeria. Int J Sci Eng Res 2012;3:1–4.
[70] Saxena RC, Adhikari DK, Goyal HB. Biomass-based energy fuel through biochemical routes: a review. Renew Sustain Energy Rev 2009;13:156–67.
[71] Lora ES, Andrade RV. Biomass as energy source in Brazil. Renew Sustain Energy Rev 2009;13:777–88.
[72] Jensen PD, Mattsson JE, Kofman PD, Klausner A. Tendency of wood fuels from whole trees, logging residues and roundwood to bridge over openings. Biomass Bioenergy 2004;26:107–13.

[73] Demirbas MF, Balat M, Balat H. Potential contribution of biomass to the sustainable energy development. Energy Convers Manag 2009;50:1746–60.
[74] Vamvuka D. Bio-oil, solid and gaseous biofuels from biomass pyrolysis processes-An overview. Int J Energy Res 2011;35:835–62.
[75] Li Z, Yin F, Li H, Wang X, Lian J. A novel test method for evaluating the methane gas permeability of biogas storage membrane. Renew Energy 2013;60:572–7.
[76] Serrano-Lotina A, Daza L. Highly stable and active catalyst for hydrogen production from biogas. J Power Sour 2013;238:81–6.
[77] Muffler K, Ulber R. Use of renewable raw materials in the chemical industry —Beyond sugar and starch. Chem Eng Technol 2008;31:638–46.
[78] Balat M, Balat H. Recent trends in global production and utilization of bio-ethanol fuel. Appl Energy 2009;86:2273–82.
[79] Demirbas A. Progress and recent trends in biofuels. Prog Energy Combus Sci 2007;33:1–18.
[80] Philp JC, Guy K, Ritchie RJ. Biofuels development and the policy regime. Trends Biotechnol 2013;31:4–6.
[81] Tan KT, Lee KT, Mohamed AR. Role of energy policy in renewable energy accomplishment: the case of second-generation bioethanol. Energy Policy 2008;36:3360–5.
[82] Adeoti O, Ayelegun TA, Osho SO. Nigeria biogas potential from livestock manure and its estimated climate value. Renew Sustain Energy Rev 2014;37:243–8.
[83] Ajao KR, Ajimotokan HA, Popoola OT, Akande HF. Electric energy supply in Nigeria, decentralized energy approach. Cogener Distrib Gener J 2009;24:34–50.
[84] Iye EL, Bilsborrow PE. Assessment of the availability of agricultural residues on a zonal basis for medium- to large-scale bioenergy production in Nigeria. Biomass Bioenergy 2013;48:66–74.
[85] Ishola MM, Brandberg T, Sanni SA, Taherzadeh MJ. Biofuels in Nigeria: a critical and strategic evaluation. Renew Energy 2013;55:554–60.
[86] Piccolo C, Bezzo F. A techno-economic comparison between two technologies for bioethanol production from lignocellulose. Biomass Bioenergy 2009;33:478–91.
[87] Gressel J. Transgenics are imperative for biofuel crops. Plant Sci 2008;174:246–63.
[88] Sticklen M. Plant genetic engineering to improve biomass characteristics for biofuels. Curr Opin Biotechnol 2006;17:315–9.
[89] Sticklen MB. Plant genetic engineering for biofuel production: towards affordable cellulosic ethanol (Retraction of vol. 9, pg 433, 2008). Nat Rev Gene 2010;11:308.
[90] Eijsink VGH, Vaaje-Kolstad G, Varum KM, Horn SJ. Towards new enzymes for biofuels: lessons from chitinase research. Trends Biotechnol 2008;26:228–35.
[91] Ituen EE, John NM, Bassey BE. Biogas Production from Organic Waste in Akwa IBOM State of Nigeria. In: Yanful E, editor. Appropriate Technologies for Environmental Protection in the Developing World. Netherlands: Springer; 2009. p. 93–9.
[92] Iye E, Bilsborrow P. Cellulosic ethanol production from agricultural residues in Nigeria. Energy Policy 2013;63:207–14.
[93] Ogunjobi JK, Lajide L. The potentials of cocoa pods and plantain peels as renewable sources in Nigeria. Int J Green Energy 2013;12:440–5.
[94] Suberu MY, Bashir N, Mustafa MW. Biogenic waste methane emissions and methane optimization for bioelectricity in Nigeria. Renew Sustain Energy Rev 2013;25:643–54.
[95] Klom AM. Electricity Deregulation in the European Union. Energy in Europe: energy policies and trends in the European Community. 1996:28–37.
[96] Dada JO. Web-services-based architecture for information integration in Nigeria deregulated electricity market environment. Int J Comput Appl 2014;87:1–8.
[97] Dada JO, Kochs H-D. Xml-based open electricity market information exchange network using object-oriented methods. Int J Comput Appl 2005;27:153–60.
[98] Ajayi A, Anyanechi C, Sowande S, Marie Phido T. A guide to the nigerian power sector. KPMG Nigeria. 2013: pp. 1–27.
[99] NERC. Regulations for Independent Electricity Distribution Networks. 2012.
[100] Bala EJ. RENEWABLE ENERGY POLICY & MASTERPLAN FOR NIGERIA. Energy Commission of NIgeria Available from: ⟨http://wwwenergygovng/indexphp?option=com_docman&task=doc_download&gid=89&Itemid=49⟩. 2012.
[101] Sambo AS. Renewable energy development in Nigeria. World Future Council strategy Workshop on Renewable Energy 2010.
[102] Akuru UB, Okoro OI. Renewable energy investment in Nigeria: a review of the renewable energy master plan. In: Proceedings of the IEEE International Energy Conference and Exhibition (EnergyCon) 2010. pp. 166–71.
[103] Oyedepo S. Energy and sustainable development in Nigeria: the way forward. Energy Sustain Soc 2012;2:1–17.
[104] Sambo AS. Matching electricity supply with demand in Nigeria. Int Assoc Energy Econ 2008:32–6.
[105] Galadima A, Garba ZN, Ibrahim BM, Almustapha MN, Leke L, Adam IK. Biofuels production in Nigeria: the policy and public opinions. J Sustain Dev 2011;4.
[106] Couture T, Gagnon Y. An analysis of feed-in tariff remuneration models: implications for renewable energy investment. Energy Policy 2010;38:955–65.
[107] Del Río P, Gual MA. An integrated assessment of the feed-in tariff system in Spain. Energy Policy 2007;35:994–1012.
[108] Yatchew A, Baziliauskas A. Ontario feed-in-tariff programs. Energy Policy 2011;39:3885–93.
[109] Bugaje IM. Renewable energy for sustainable development in Africa: a review. Renew Sustain Energy Rev 2006;10:603–12.
[110] Pegels A. Renewable energy in South Africa: potentials, barriers and options for support. Energy Policy 2010;38:4945–54.
[111] Krupa J, Burch S. A new energy future for South Africa: the political ecology of South African renewable energy. Energy Policy 2011;39:6254–61.
[112] Msimanga B, Sebitosi AB. South Africa's non-policy driven options for renewable energy development. Renew Energy 2014;69:420–7.
[113] Walwyn DR, Brent AC. Renewable energy gathers steam in South Africa. Renew Sustain Energy Rev 2015;41:390–401.
[114] South African Renewable Energy Feed-in Tariff. 2015.
[115] Abanda FH. Renewable energy sources in Cameroon: potentials, benefits and enabling environment. Renew Sustain Energy Rev 2012;16:4557–62.
[116] Cameroun: Plan d'action national d' e´nergie pour la re´duction de la pauvrete´, Energy management assistance programme (ESMAP). World Bank; 2005.
[117] Dasappa S. Potential of biomass energy for electricity generation in sub-Saharan African. Energy Sustain Dev 2011;15:203–13.
[118] Nkue V, Njomo D. Analyse du systeme e´nerge´tique Camerounais dans une perspective de de´veloppement soutenable. Revue de l'Energie 2009;588:102–14.
[119] Tchinda R, Kaptouom E. Situation des energies nouvelles et renouvelables au Cameroun. Revue de l'Energie 1999;510:653–8.
[120] Tansi B. An assessment of Cameroon's renewable energy resource and prospect for a sustainable economic development. Germany: Brandenburg Technical University; 2011.
[121] Tchinda R, Kendjio J, Kaptouom E, Njomo D. Estimation of mean wind energy available in far north Cameroon. Energy Convers Manag 2000;41:1917–29.
[122] Tchinda R, Kaptouom E. Wind energy in Adamaoua and North Cameroon provinces. Energy Convers Manag 2003;44:845–57.
[123] ISH. International small-hydro atlas. 2015.
[124] Wirba AV, Abubakar Mas'ud A, Muhammad-Sukki F, Ahmad S, Mat Tahar R, Abdul Rahim R, et al. Renewable energy potentials in Cameroon: prospects and challenges. Renew Energy 2015;76:560–5.
[125] Ackom EK, Alemagi D, Ackom NB, Minang PA, Tchoundjeu Z. Modern bioenergy from agricultural and forestry residues in Cameroon: potential, challenges and the way forward. Energy Policy 2013;63:101–13.
[126] Nfah EM, Ngundam JM. Identification of stakeholders for sustainable renewable energy applications in Cameroon. Renew Sustain Energy Rev 2012;16:4661–6.
[127] Wereko-Brobby CY, Mintah IK. Ghana's renewable energy development programme. In: Sayigh AAM, editor. Energy Conservation in Buildings. Oxford: Pergamon; 1991. p. 172–6.
[128] Serwaa Mensah G, Kemausuor F, Brew-Hammond A. Energy access indicators and trends in Ghana. Renew Sustain Energy Rev 2014;30:317–23.
[129] Adom PK, Kwakwa PA. Effects of changing trade structure and technical characteristics of the manufacturing sector on energy intensity in Ghana. Renew Sustain Energy Rev 2014;35:475–83.
[130] Arthur R, Baidoo MF, Antwi E. Biogas as a potential renewable energy source: a Ghanaian case study. Renew Energy 2011;36:1510–6.
[131] EC. Energy statistics; 2000–2008 [Ghana]. Energy Commission.
[132] Bensah EC, Brew-Hammond A. Biogas technology dissemination in Ghana: history, current status, future prospects, and policy significance. Int J Energy Environ 2010;1:277–94.
[133] Alzola JA, Vechiu I, Camblong H, Santos M, Sall M, Sow G. Microgrids project, Part 2: Design of an electrification kit with high content of renewable energy sources in Senegal. Renew Energy 2009;34:2151–9.
[134] Camblong H, Sarr J, Niang AT, Curea O, Alzola JA, Sylla EH, et al. Micro-grids project, Part 1: analysis of rural electrification with high content of renewable energy sources in Senegal. Renew Energy 2009;34:2141–50.
[135] Youm I, Sarr J, Sall M, Kane MM. Renewable energy activities in Senegal: a review. Renew Sustain Energy Rev 2000;4:75–89.
[136] REEEP Policy Database, Available from: ⟨http://www.reegle.info/policy-and-regulatory-overviews/SN⟩. 2014.
[137] Vilar. Renewable energy in West Africa: Status, experiences and trends. In: Vilar, editor.: Ecowas centre for renewable energy and energy efficiency (ECREEE). Renewable energy department, canary island institute of technology (ITC). Economy and business area, CASA ÁFRICA; 2012. p. 1–346.
[138] Amin AZ. Amin, Senegal renewables readiness assessment. The International Renewable Energy Agency (IRENA), Available from: ⟨http://www.irena.org/DocumentDownloads/Publications/IRENA%20Senegal%20RRA.pdf⟩; 2012. 1–76.
[139] Thiam DR. Renewable decentralized in developing countries: appraisal from microgrids project in Senegal. Renew Energy 2010:1615–23.
[140] Panwar NL, Kaushik SC, Kothari S. Role of renewable energy sources in environmental protection: a review. Renew Sustain Energy Rev 2011:1513–24.
[141] Thiam DR. Renewable energy, poverty alleviation and developing nations: evidence from Senegal. J Energy in Southern Africa 2011;22:23–34.
[142] Hwang JJ. Promotional policy for renewable energy development in Taiwan. Renew Sustain Energy Rev 2010;14:1079–87.