Bioenergy technology development in Nigeria –pathway to sustainable energy development

Article *in* International Journal of Environment and Sustainable Development · January 2019

Bioenergy technology development in Nigeria – pathway to sustainable energy development

Sunday O. Oyedepo*

Department of Mechanical Engineering,
Covenant University, Nigeria
Email: Sunday.oyedepo@covenantuniversity.edu.ng
*Corresponding author

Israel S. Dunmade

Mount Royal University,
Calgary, Canada
Email: israel_dunmade@yahoo.ca

Tunde Adekeye and Ahme A. Attabo

Department of Mechanical Engineering,
Covenant University, Nigeria
Email: tundeadekeye2008@gmail.com
Email: ameh2a@yahoo.com

Olukunle C. Olawole

Department of Physics,
Covenant University, Nigeria
Email: olukunle.olawole@covenantuniversity.edu.ng

Philip O. Babalola

Department of Mechanical Engineering,
Covenant University, Nigeria
Email: Phillip.babalola@covenantuniversity.edu.ng

Joseph A. Oyebanji

Department of Mechanical Engineering,
Bells University of Technology, Nigeria
Email: banjijoe@yahoo.com

Mfon O. Udo, Oluwaseun Kilanko and Richard O. Leramo

Department of Mechanical Engineering,
Covenant University, Nigeria
Email: mfon.udo@covenantuniversity.edu.ng
Email: Oluwaseun.kilanko@covenantuniversity.edu.ng
Email: Richard.leramo@covenantuniversity.edu.ng

Abstract: In Nigeria, high and outrageous energy cost constitutes a serious challenge to all aspects of the economy. And this has been a subject of concern in the country over a period of time. A dependable and renewable energy source is of utmost desire to strengthen the nation's economy and this urgent need cannot be overlooked. As a result of the erratic and expensive power supply to the national grid, it has become ultimately necessary to search for other inexpensive sources of energy to meet the ever increasing energy needs for rural and urban dwellers. In view of the above energy situation in Nigeria, this paper aimed at carrying out a comprehensive review on bioenergy technology option as a pathway to achieving sustainable energy development in the country. The potential, current progressive stages, and prospects of bioenergy conversion techniques, in the Nigeria context, are discussed. The barriers to bioenergy technology development in Nigeria with possible solutions are also presented.

Keywords: bioenergy technology; BET; renewable energy; energy sector; sustainable development.

Reference to this paper should be made as follows: Oyedepo, S.O., Dunmade, I.S., Adekeye, T., Attabo, A.A., Olawole, O.C., Babalola, P.O., Oyebanji, J.A., Udo, M.O., Kilanko, O. and Leramo, R.O. (2019) 'Bioenergy technology development in Nigeria – pathway to sustainable energy development', *Int. J. Environment and Sustainable Development*, Vol. 18, No. 2, pp.175–205.

Biographical notes: Sunday O. Oyedepo is a Professor in the Department of Mechanical Engineering, Covenant University, Nigeria. His PhD research work was on 'Thermodynamic performance analysis of selected gas turbine power plants in Nigeria'. He has published over 75 papers in national/international journals, conferences and book chapters. His major contributions in the area of energy systems and environmental noise is the publication of research and review papers in leading journals, i.e., *Renewable and Sustainable Energy Reviews, Energy Conversion and Management*, *Energy Exploration & Exploitation*, *Environmental Monitoring Assessment* and *Journal of Environmental Studies*. His research interests include but not limited to: thermal system design and optimisation, energy management and energy conversion systems, heat transfer analysis, etc. He is a Registered Engineer in Nigeria and a member of Nigerian Society of Engineers.

Israel S. Dunmade is a Professor in the Earth and Environmental Sciences Department at the Mount Royal University, Calgary, Canada. He also has an affiliation with Mechanical Engineering Department at the Covenant University, Ota, Nigeria. He obtained his Master's in Mechanical Engineering and Doctoral in Environmental and Process Engineering. He is a Certified Professional Engineer, Project Management Professional and Environmental Professional. He has served on the boards of a number of professional

organisations and on the editorial boards of academic journals. Among them is the Board of Canadian Society for Bioengineering Foundation and as the Editor of *International Journal of Biodiversity and Forestry*. His research interests include sustainable infrastructure, lifecycle engineering, renewable resources, sustainable design and manufacturing, technology transfer, campus and rural sustainability, and eco-industrial systems modelling. He also enjoys reading, driving and tennis.

Tunde Adekeye obtained his PGD and MTech (Mechanical Engineering, Thermofluid Option) from the Ladoke Akintola University, Ogbomoso, Nigeria. His research interests are on thermo fluid and energy conversion systems. He was a Senior Technologist in the Department of Mechanical Engineering, Covenant University, Nigeria. He is currently pursuing his PhD program at Ladoke Akintola University. He is a Registered Engineer with the Council for the regulation of Engineering in Nigeria (COREN).

Ahme A. Attabo is a research student at the Covenant University Ota with interest in renewable energy and thermo-fluids. He holds a Master's in Mechanical Engineering from the same university and he is currently pursuing his PhD research program. Some works carried out by him includes the thermodynamics assessment of the effects of nano fluids on vapour compression systems, evaluation of a hybrid wind and solar system in Northern Nigeria and other energy related publications. He also has over ten years of field experience working for an international oil and gas company based in the Niger-delta region of Nigeria functioning as a technical support staff. He has been adding value to the company by reducing equipment downtime and improving the integrity of fixed equipment/vessels using appropriate monitoring techniques.

Olukunle C. Olawole received his MSc in Solid State Physics from the University of Ibadan, Nigeria in 2011. He is at the tail end of his PhD in Renewable Energy/Material Science in the Department of Physics, Covenant University Ota, Nigeria. He has been working on harnessing the potency of renewable energy to solve the epileptic power supply in Nigeria. Specifically, work is on-going in the field of harvesting the solar radiation in the sunlight by concentrating it onto a concentrator, and thereafter converting it to usable electricity through the underlying principle of the science of energy band theory via thermionic engine whose electrodes are equipped with nanomaterials. In addition, he has been studying the sensitivity of graphene and carbon nanotubes to optics and its application in advancing the field of science and nano-engineering.

Philip O. Babalola is a Lecturer and Researcher at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. He holds a PhD in Mechanical Engineering from the prestigious Covenant University, in Ota, Nigeria. He specialises in research on composite materials, renewable energy applications, thermo-fluid and artificial neural network with significant publications. Some of his teaching areas are engineering materials, advanced composite materials, internal combustion engines, fluid mechanics, building services engineering and engineering law and entrepreneurship. He is a registered member of the Council for Regulation of Engineering in Nigeria and corporate member of the Nigerian Society of Engineers.

Joseph A. Oyebanji is a Senior Technologist in the Department of Mechanical Engineering, Bells University of Technology, Nigeria. His research areas of interest cover lignocellulosic fuels and products, and ionic liquids, computational fluid dynamics, heat and mass transfer, refrigeration and

air-conditioning, and energy technique/study. He attended Ladoke Akintola University of Technology for Master's in Mechanical Engineering (Thermo-fluid) and Federal University of Technology Akure for PGD in Mechanical Engineering. He is a registered member of the Council for Regulation of Engineering in Nigeria and a member of the Nigeria Institution of Mechanical Engineers (NimechE).

Mfon O. Udo holds a BTech in Mechanical Engineering from the University of Science and Technology, Port Harcourt, MSc in Mechanical Engineering and PhD in Metallurgical and Materials Engineering from the University of Lagos. He is a member of the Nigerian Society of Engineers and registered with the Council for Regulation of Engineering in Nigeria (COREN). He worked with the Federal Ministry of Works and Housing and then lectured in the department of Marine Engineering of the Federal College of Fisheries and Marine Technology, Lagos. He has three journal publications and a textbook in engineering drawing being published so far.

Oluwaseun Kilanko holds a BSc and MSc in Mechanical Engineering from the University of Ibadan and he bagged his PhD in Mechanical Engineering from the Covenant University in 2016. He is a Lecturer and Researcher at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. He specialises in research on machine design, manufacturing engineering, modelling and simulation with significant publications. He is a registered member of the Council for Regulation of Engineering in Nigeria and corporate member of the Nigerian Society of Engineers.

Richard O. Leramo holds a BEng and MSc in Mechanical Engineering from the University of Ilorin and University of Ibadan, respectively. He bagged his PhD in Mechanical Engineering from the Covenant University in 2017. He is a Lecturer and researcher at the Department of Mechanical Engineering, Covenant University, Ota, Ogun State, Nigeria. He specialises in research on machine design, manufacturing engineering, CAD/CAM, modelling and simulation with significant publications. He is a registered member of the Council for Regulation of Engineering in Nigeria and corporate member of the Nigerian Society of Engineers.

This paper is a revised and expanded version of a paper entitled 'Bioenergy technology development in Nigeria – pathway to sustainable energy development' presented at International Conference of Engineering for Sustainable World (ICESW2017), Covenant University, Nigeria, 3–7 July 2017.

1 Introduction

Energy is the mainstay of Nigeria's economic growth and development. It plays a significant role in the nation's international diplomacy and it serves as a tradable commodity for earning the national income, which is used to support government development programmes. It also serves as an input into the production of goods and services in the nation's industry, transport, agriculture, health and education sectors, as well as an instrument for politics, security and diplomacy (Oyedepo, 2012).

The increasing global energy demand and the adverse effects of non-renewable fossil fuels on environment had motivated considerable research attention in a wide range of engineering application of renewable resources such as biomass (Adaramola et al., 2011). Biomass technology offers an attractive platform to utilise certain categories of biomass for meeting both urban and rural energy needs if it is properly harnessed. In our rural areas, various cellulosic biomasses (cattle dung, agricultural waste) are available which can be utilised in the production of bioenergy (Mamun et al., 2009). It has been established that the by-product of biomass found in urban and industrial areas constitute wastes and inadequate management of these wastes result in many untold urban and environmental health hazards in developing countries such as Nigeria. Energy from these wastes, thus has the ability of providing employment opportunities and improving the economy of the nation instead of constituting environmental pollutants (Sambo, 2005).

Recently, investigation established that fossil fuel is fast becoming scarce and limited in terms of availability in the world. The developed and developing countries such as China, India, Nigeria, etc., have seen the need for alternative, sustained (renewed) forms of energy to meet the ever-increasing demand for basic needs by the rural and urban dwellers and therefore gave strong support for it. In 2011, USA, Brazil and European Union were responsible for 48%, 22% and 17% respectively of the world biofuel production (GRFA, 2013).

At world assessment, above half of the human population are denied accessibility to new alternative form of energy. Majority of these people reside in underdeveloped countries and are predominantly poor. They absolutely relied on the primitive biomass sources. This has resulted to health hazards and many untold risks. The overall objective of the global energy strategy, hence, has focused at moving from the expensive and unfriendly fossil fuels to inexpensive, abundance renewable form of energy which could be from biomass, wind, hydro, geothermal and solar forms of energy just to mention a few (Dawit, 2012).

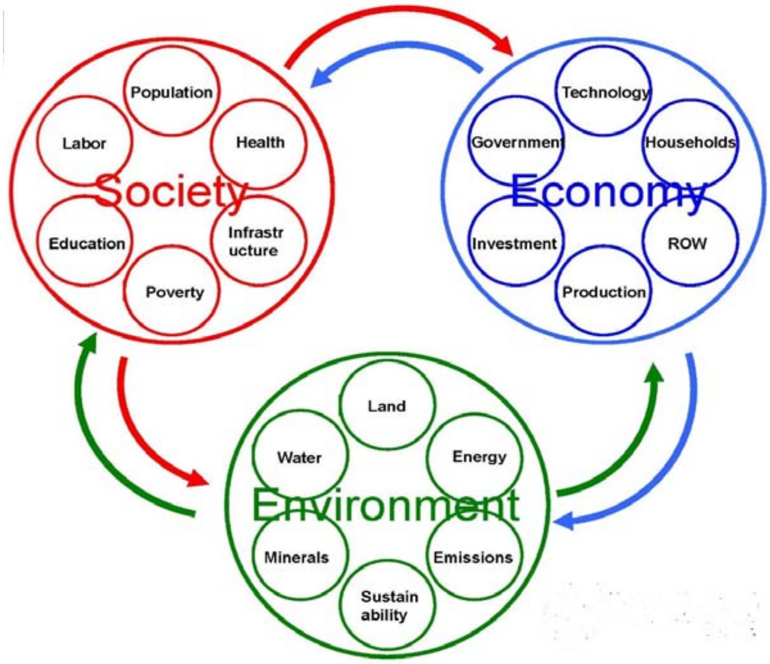
A sustainable energy system may be regarded as a cost-efficient, reliable, and environment-friendly energy system that effectively utilises local resources and networks. It is not 'slow and inert' like a conventional energy system, but it is flexible in terms of new techno-economic and political solutions. The introduction of new solutions is also actively promoted (Oyedepo, 2012).

Access to clean, secure, sustainable, affordable and reliable energy has been a cornerstone of the world's increasing prosperity and economic growth. And this is a prerequisite for sustainable development in developing countries such as Nigeria. Energy sufficiency and security is a key to development and prosperity since it provides essential inputs for socio-economic development at regional, national and sub-national levels; thereby providing vital services that improve the quality of life (Singh and Sooch, 2004). Figure 1 shows the interrelationships between access to energy and sustainable development. The access to affordable energy is an essential component of achieving the Millennium Development Goals and UN Sustainable Development Goals for Nigeria (Amigun et al., 2011; Mohamad and Anuge, 2016).

The demand for sustainable energy in Nigeria is increasing due to population and developmental growth. Unfortunately, the available infrastructures for providing and extending this required energy especially to rural areas have continued to diminish and have become grossly inadequate in recent times. Moreover, the persistent energy crisis in Nigeria has weakened industrialisation in the country. This has significantly undermined efforts to achieve sustained economic growth, increased competitiveness of indigenous industries in domestic, regional and global markets as well as employment generation

(Iwayemi, 2008). The realisation of this fact necessitates the need for the nation to identify and promote the development and utilisation of alternative sources of energy such as biomass to augment the existing ones for the socio-economic development of the unreached rural areas of Nigeria. Many researchers have looked into the availability and potential of biomass energy resources in Nigeria with a view to establishing their viability and utilisation as sources of energy (gaseous, liquid or solid fuel) in the country. Oyebanji et al. (2017) investigated chemical composition of bio-oils produced by fast pyrolysis of two energy biomass. In the study, bio-oils from fast pyrolysis of West African cordia (Cm) and Africana birch (Al) sawdust were analysed using a gas chromatography-mass spectrometry (GC-MS) analyser. Result of the study established that pyro-fuel not only can be used as fuel but can also be purified and serve as raw materials for chemical and processing industries.

Figure 1 Interrelationships between access to energy and sustainable development (see online version for colours)



Source: Amigun et al. (2011)

Exploration of the potential of biodegradable organic waste as a source of methane gas for electricity generation in Nigeria was carried out by Amasuomo and Ojukonsi (2015). In the study, a laboratory experiment was conducted using biodegradable organic solid waste collected from selected location in Nigeria. Results of the study revealed that anaerobic digestion could play a major role towards the attainment of sustainable solid waste management in Nigeria. The laboratory sample of 10 grams of solid waste produced about 0.796 litres of methane gas, and this implies that 1 tonne of organic waste in Nigeria will generate about 79,600 litres of methane gas with energy equivalent of about 1.592 MJ. Ozoegwu et al. (2017) assessed biomass and bioenergy potential of cassava waste in Nigeria. The aim of the study was to review the history, production, food value, economic value and bio-energy value of cassava. In the study, procedure for estimating cassava non-food biomass (CnFB) from harvest data was established. The procedure entailed use of statistical sampling and regression analysis to establish scaling factors for transforming the data to CnFB. A real case study reflected very accurate and statistically significant error indices. The factors and literature data were used to make long-term projections of CnFB potential of Nigeria.

The potentials of microalgae biodiesel production in Nigeria was investigated by Ogbonna et al. (2015). The study showed that Nigeria has enabling environment for large-scale microalgae cultivation but lacks the policy framework that translates to effective production and utilisation of biodiesel. The authors concluded that, with the species of microalgae already isolated which contains more than 50% oil and assuming biomass productivity of 30 $g/m^2.d$ in a 10 cm deep open pond on a plot of land (50 m × 100 m) will yield 75 kg of oil every day.

Garba and Umar Zangina (2015) assessed the quantity of rice straw and husk produced as potential sources for mini-grid rural electricity in Nigeria. The study showed that Nigeria has the potential to produce 434.6 million t of rice straw and 0.9 million t of rice husk that could be used to generate 337.67 MW/ yr of electric power at a conversion rate (rice straw and rice husk to power) of 1.7 kg of rice husks/straw per kWh of electricity, which represents about 7.64% of the current country's current power output.

Assessment of biogas energy use in Nigeria was carried out by Akinbami (2001). The study indicated that the identified feedstock substrate for an economically feasible biogas program in Nigeria includes water lettuce, water hyacinth, dung, cassava leaves, urban refuse, solid (including industrial) waste, agricultural residues, and sewage. The authors' views include the following: Nigeria produces about 227,500 tonnes of fresh animal wastes daily. Since 1 kg of fresh animal wastes produces about 0.03 m^3 gas, then Nigeria could produce about 6.8 million m^3 of biogas every day. In addition to all these, 20 kg of municipal solid wastes (MSW) per capital has been estimated to be generated in the country annually.

Audu and Aluyor (2012) examined the potentials of bioenergy and biofuels technology development in Nigeria. The study revealed that the co-production of biomass-based Fischer-Tropsch liquids and power could be an important step in a strategy to increase the contribution of bio-energy in the supply of energy in Nigeria. Fischer-Tropsch liquids – (diesel and gasoline) could be introduced in the medium term, profiting from their compatibility with current fuel delivery infrastructure, and vehicle technologies.

Balogun (2015) carried out a study on the potentials for sustainable commercial biofuels production in Nigeria. The author recommended the implementation of national policy on biofuels and incentives, backed with required political – will, will ensure compliance on the delineation between crops, which should and should not be used for biofuel production, and as such, substantially puts to rest the anxiety over 'food for fuel' belief.

Simonyan and Fashina (2013) reviewed the biomass resources available in Nigeria and the potential of generating electricity from them. The authors also evaluated various biomass energy conversion technologies and the application of these technologies to development of Nigeria. The study showed that there exist great opportunities for exploitation of different types of biomass in Nigeria with an estimated 2.01 EJ (47.97 MTOE) biomass residues and wastes available to be exploited annually.

Moreover, the conversion of biomass to energy will be rewarding, given the large availability of the biomass resources in the country.

A comprehensive review of biomass resources and biofuel production potential in Nigeria was carried out by Agbro and Ogie (2012). In the study, the biomass resources considered include agricultural crops, agricultural crop residues, forestry resources, MSW and animal waste. It was concluded that given the large availability of biomass resources in Nigeria there is immense potential for biofuel production from these biomass resources. The authors recommended that the government as well as private investors are to take practical steps towards investing in agriculture for the production of energy crops and the establishment of biofuel-processing plants in Nigeria. Nwaokocha and Giwa (2016) carried out investigation of bio-waste as alternative fuel for cooking in Nigeria. The study was carried out using binders (starch and spent oil) and biomass (rice husk and sawdust) to produce refuse derived fuel (RDF). After the production of the RDF from rice husk, moisture content, ash content, higher heating value, and tensile strength of 0.908%, 11.5%, 6160.7 kJ/kg and 508.7 N/mm^2, respectively, were obtained. Also, for the RDF produced from sawdust, moisture content of 0.93%, ash content of 16.5%, higher heating of 7,808.1 kJ/kg and tensile strength of 576.8 N/mm^2 were measured. These results showed that the RDF for rice husk seems to be a good substitute to wood as cooking fuel and would also reduce greenhouse gas emissions and thus save our environment from effects of climate change.

In view of the above facts of abundant availability of renewable energy sources in Nigeria but low accessibility to clean energy by the teeming population, converting the huge quantities of biomass resources, mostly in the form of agricultural residues and wastes (animal, food or municipal), which are currently disposed by burning or dumping, to energy production could potentially increase the energy supply thereby increasing energy mix and balance in Nigeria. In addition, there are environmental benefits of reducing greenhouse gas emissions by generating clean energy from biomass as well as supply of electricity in the rural areas. Poverty rate will also be alleviated (Simonyan and Fasina, 2013). The prime objectives of this paper are:

- to review the potentials of energy sources in Nigeria and its energy situation
- to review the current status and potentials of bioenergy technology (BET)
- to assess possibility of utilising biomass to generate alternative energy sources (fuels and electricity)
- to identify possible prospects and challenges in development of BETs in Nigeria.

2 Overview of energy sources and current energy situation in Nigeria

Nigeria is rich in both conventional and renewable energy resources that empower the country with a large capacity to develop an effective national energy policy. Presently, the country depends mostly on conventional source of energy with quite high opportunity cost making it cost-wise comparatively inaccessible for the poor population most especially the rural dwellers (Anowor et al., 2014). Worldwide, the country is ranked as the 10th largest crude oil producer with fossil fuels reserve estimates of about 37.140 billion barrels of crude oil (produces about 2.5 million barrels of crude oil per day), 182 trillion cubic feet (ft^3) of natural gas, and 209 million short tons of coal

(Maijama'a et al., 2015; Onochie et al., 2015). Table 1 shows details available conventional energy reserves in Nigeria. With these statistics, it is obvious that Nigeria is a significant contributor to the world's fossil-based energy consumption. However, production of energy for local use is still abysmally low (Giwa et al., 2017). The quality of electricity services in Nigeria remains poor and many Nigerians are still without access to regular electricity (Emodi and Yusuf, 2015).

Table 1 Nigeria fossil fuel energy reserves

Resources type	*Reserves*	
	Natural units	*Energy units (Btoe)*
Natural gas	187 trillion SCP	4.19
Crude oil	36.22 billion barrels	5.03
Tar sand	31 billion barrels equivalent	4.31
Coal and lignite	2.175 billion tonnes	1.52

Source: Ozoegwu et al. (2017)

While energy either from conventional or renewable sources is needed to generate electricity for both economic and household sectors, one of the most important challenges Nigeria is facing for the past two decades is sustainable power supply (Maijama'a et al., 2015). The country has been facing persistent electricity problems ranging from power generation down to transmission and distribution. The gap between the electricity demand and supply has far exceeded that of any other country in the world. Nigeria is faced with chronic electricity crisis that has resulted in the crippling of most sectors of the economy.

Table 2 The renewable energy reserves in Nigeria

Energy sources	*Reserves*
Small hydropower	3,500 MW
Large hydropower	11,250 MW
Wind	2–4 m/s at 10 m in height (main land)
Solar radiation	3.5–7.0 kWh/m^2/day (4.2 million MWh/day using 0.1% land area)
Animal waste	211 million assorted animal (285.065 million tons/yr of production)
Energy crops and agriculture residue	28.2 million hectares of arable land (30% of total land)
Crop residue	83 million tons/yr
Fuel wood	11 million hectares of forest and wood land
Wave and tidal energy	150,000 TJ/(1,759.6 toe/yr)

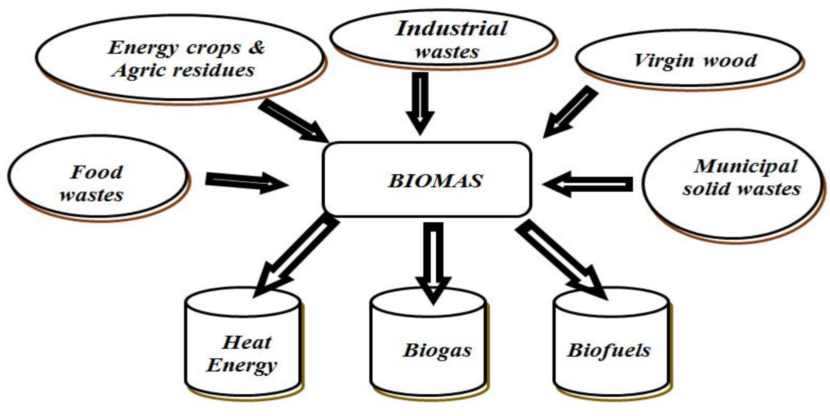
Source: Ozoegwu et al. (2017)

Development based on fossil fuels is basically unsustainable. There is therefore a call for sustainable development based on renewable energy sources. Table 2 presents available renewable energy sources in Nigeria. For maximum benefit and utilisation of vast available renewable resources, the over-dependence of the energy sector on fossil fuel that has slowed down the development of alternative fuels must be reversed (Giwa et al., 2017). 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 biomass which are abundant all over the country. As a renewable energy source, biomass products are sustainable, limitless and environment friendly. Bioenergy sources have significant potential to improve and make a difference on the low level access to clean energy and electricity in Nigeria (Aliyu et al., 2015). In addition to the problem of finite and fast depleting nature of fossil fuel, the adverse environmental impacts of fossil fuels, and deterioration of electricity transmission and distribution facilities have necessitated urgent massive investment in decentralised renewable energy technology (especially BET) (Chindo et al., 2014; Ozoegwu et al., 2017). This is possibly for Nigeria's energy security and environmental preservation.

3 Overview of biomass energy source

Biomass refers to energy derivable from sources of plant origin such as trees, grasses, agricultural crops and their derivatives, as well as animal wastes, wastes from food processing, aquatic plants and algae (Duku et al., 2011). As an energy resource, biomass may be used as solid fuel, or converted via a variety of technologies (biofuel or biogas) to liquid or gaseous forms for the generation of electric power, heat or fuel for motive power. Biomass resources are considered renewable as they are naturally occurring and when properly managed, may be harvested without significant depletion. Generally, sources of biomass as presented in Figure 2 include virgin wood (fuel wood), energy crops and agricultural residues, industrial wastes/effluents, MSW, food wastes, etc. (Sambo, 2009; Akorede et al., 2017).

Figure 2 Biomass sources and products (see online version for colours)



Generally, biomass is compounds of carbon, oxygen, nitrogen and sulphur, with significant amounts of free energy in the form of chemical bonds (Aliyu et al., 2015). Depend on the type, when combusted, the chemical energy in biomass is released 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, which can either be solid, gas or in liquid form. Liquid biofuels can either be first-generation or second-generation biofuels. First-generation biofuels are made from sugars, grains or seeds using only a specific, often edible part of the above ground biomass. Examples of first generation biofuels are sugarcane ethanol, starch-based or corn ethanol, biodiesel, and pure plant oil. Second-generation biofuel is generally made from lignocellulosic biomass, also called cellulosic biomass (OECD/IEA, 2010). The suitability of a particular biomass as a potential feedstock for biofuels production depends on various characteristics such as moisture content, calorific value, fixed carbon, oxygen, hydrogen, nitrogen, volatiles, ash content, and cellulose/lignin ratio. Generally, cellulose is the largest fraction, and constitutes about 38–50% of the biomass by weight (Duku et al., 2011).

Biomass feedstocks can be obtained from conventional agricultural products (such as sugar- or starch-rich crops, and oilseeds) and lignocellulosic products and residues (Girard and Fallot, 2006). Lignocellulosic feedstocks (such as trees, shrubs, grasses, agricultural and forest residues) are potentially more abundant and cheaper than feedstock from conventional agriculture because they can be produced with fewer resources and on marginal and poor lands.

3.1 Global potential of biomass as a renewable energy source

The present final energy from biomass is about 50 EJ of energy or 14% of the world's final energy use (WEC, 2016). According to WBA (2014), the realistic potential for final energy from biomass worldwide would increase to 150 EJ by 2035. Based on the survey carried out by IRENA (2014), about 38–45% of total supply is estimated to originate from agricultural residues and waste while the remaining supply is shared between energy crops and forestry products and residues. The estimated potential of using agricultural residues for energy ranges from 17 EJ to 128 EJ. This high range of values is due to the dependence on various factors including moisture content, energy content of the residues etc. The highest potential for using agricultural residues is in Asia and Americas due to the high production of rice and maize respectively (WEC, 2016).

Globally, bioenergy (including waste) accounted for 14% of the world's energy consumption in 2012 with roughly 2.6 billion people dependent on traditional biomass for energy needs. The consumption pattern of bioenergy varies geographically. USA and Brazil lead the world in production and consumption of liquid biofuels for transport (accounting for almost 80% of production). Liquid biofuels have been in use in many countries such as USA, Malaysia, Indonesia, Brazil, Germany, France, Italy and other European countries. However, the potential for their production and applications are much more on increase. For example, in the transport sector, the production of corn ethanol in the USA and sugarcane ethanol in Brazil has increased significantly. Table 3 shows the global production of fuel ethanol and biodiesel from 2004–2008. It is observed that the USA, Brazil, and China account for over 90% of global ethanol production. The production of ethanol in the USA, as the largest producer of ethanol increased from about 13 billion litres in 2004 to 34 billion litres in 2008 (Shikida, 2014; Govinda and Ashish, 2010).

Worldwide biodiesel production increased from 2.3 billion litres in 2004 to 14.7 billion litres in 2007 (OECD, 2008). The production of biodiesel in Germany, as the largest producer increased from 1.18 billion litres in 2004 to 3.28 billion litres in 2007 (Govinda and Ashish, 2010). In recent years, some countries outside Europe and the USA have begun to produce biodiesel. For example, Brazil opened its first biodiesel plant, which uses a mixture of vegetable oil and sewage as feedstock, in March 2005 (OECD-FAO, 2008).

The use of biomass for electricity is prominent in Europe and North America – predominantly produced from forestry products and residues. Cogeneration plants enable the use of biomass with increased efficiency, so much so that the combined efficiency of producing heat and electricity crosses 80%. The Europe and Americas continents contribute more than 70% of all consumption of biomass for electricity (WEC, 2016). In 2013, 462 TWh of electricity was produced globally from biomass. In the past few years, biomass is seeing increasing uptake in developing countries such as Asia and Africa where significant population lacks access to electricity. Biogas and decentralised bioenergy systems are becoming more cost competitive. Already cogeneration plants using agricultural residues like bagasse in India, Mauritius, Kenya and Ethiopia are successful.

Globally, biomass fuel is becoming ever more attractive as suitable substitute for fossil fuels due to the increasing demand for clean energy, declining fuel reserves, and its contribution towards reducing dependence on crude oil (Juliet et al., 2016).

3.2 Biomass resources and bioenergy potential in Nigeria

Based on the fact that the demand for energy is growing by the day globally, the need for exploring and exploiting new sources of energy which are renewable as well as environmentally friendly cannot be overemphasised (Juliet et al., 2016). Biomass technology offers an attractive platform to utilise certain categories of biomass for meeting both urban and rural energy needs if it is properly harnessed. There exists a huge potential for the successful deployment of biomass energy in Nigeria, most especially in the rural agricultural areas. Research revealed that, Nigeria has a reserve of 11 million hectares of forest and woodland, 245 million assorted animals in 2001 and 28.2 million hectares of arable land, which is approximately equal to 30% of the total land (Akorede et al., 2017). All these produce in excess of 1.2 million tonnes of biomass per day. Moreover, in 2005, bio-energy reserves/potential of Nigeria stood at 13 million hectares of fuelwood, 61 million tonnes per year of animal waste, and 83 million tonnes of crop residues (Agba et al., 2010).

In Nigeria rural areas, various cellulosic biomasses (cattle dung, agricultural waste) are available which can be utilised in the production of bioenergy. It has been established that the by-product of biomass found in urban and industrial areas constitute wastes and inadequate management of these wastes result in many untold urban and environmental health hazards in Nigeria. Energy from these wastes, thus has the ability of providing employment opportunities and improving the economy of the nation instead of constituting environmental pollutants (Sambo, 2005).

The type of biomass resource available in Nigeria varies with climatic region in the country. In the rain forest zone, we have woody biomass while in savannah zones we have crop residues (Olaoye, 2011). Major classifications of biomass resources are presented as follows.

Table 3 Global biofuel production from 2004–2008

Country	*Ethanol*						*Biodiesel*					
	Major feedstock	*Production capacity (billion litres)*					*Major feedstock*	*Production capacity (billion litres)*				
		2004	*2005*	*2006*	*2007*	*2008*		*2004*	*2005*	*2006*	*2007*	*2008*
US	Corn	13	15	18.3	24.6	34	Soybean	0.11	0.36	0.99	1.93	2.69
Brazil	Sugar cane	15	15	17.5	19	27	Soybean	-	-	0.07	-	1.2
Germany	Wheat	0.02	0.2	0.5	-	0.5	Rapeseed	1.18	1.9	3.02	3.28	3.2
France	Sugar beet, wheat	0.1	0.15	0.25	-	1.2	Rapeseed	0.4	0.56	0.84	0.99	2.06
China	Corn, sugar cane	2	1	1	1.8	1.9	Soybean, rapeseed	-	-	0.07	-	0.1
Argentina	Sugar cane	-	-	-	0.02	-	Soybean	-	-	-	-	1.2
Italy	Cereals	-	-	0.13	-	0.13	Oil seeds	0.36	0.45	0.51	0.41	0.68
Spain	Barley, wheat	0.2	0.3	0.4	-	0.4	Oil seeds	0.01	0.08	0.11	0.19	0.24
India	Sugar cane, wheat	-	0.3	0.3	0.2	0.3	Soybean, rapeseed	-	-	0..03	-	0.02
Canada	Wheat	0.2	0.2	0.2	0.8	0.9	Oil seeds	-	0.1	0.05	-	0.1
Poland	Rye	-	0.05	0.12	-	0.12	Rapeseed	-	0.11	0.13	0.09	0.31
Czech Rep.	Sugar beet	-	0.15	0.02	-	-	Rapeseed	0.07	0.15	0.12	0.07	0.12
Columbia	Sugar cane	-	0.2	0.2	0.3	0.3	Soybean	-	-	-	-	-
Sweden	Wheat	-	0.2	0.14	-	0.14	Rapeseed	0.002	0.001	0.01	0.07	0.11
Malaysia	-	-	-	-	-	-	Oil palm	-	-	0.14	-	-
UK	-	-	-	-	-	-	Rapeseed	0.01	0.06	0.22	0.17	0.22
Denmark	Wheat	-	0.1	-	-	-	Oil seeds	0.08	0.08	0.09	0.1	0.15
Austria	Wheat	-	0.1	-	-	-	Oil seeds	0.06	0.1	0.14	0.3	0.24
Slovakia	Corn	-	0.1	-	-	-	Oil seeds	0.02	0.09	0.09	0.05	0.17
Thailand	Sugar cane, cassava	0.2	-	-	0.3	0.3	Oil palm	-	-	-	-	0.4
Australia	Sugar cane	0.07	-	-	0.1	-	-	-	-	-	-	-
EU	Various	-	-	-	2.16	-	-	-	-	-	-	-
World total		31	33	39	49.6	67		2.3	4.1	6.9	8.4	14.7

Source: Govinda and Ashish (2010)

3.2.1 Energy crops

In Nigeria, energy crops that have potential as feedstocks for biofuel production include sugarcane, sweet sorghum, maize and cassava for ethanol, and oil palm, coconut, cotton, sunflower, soy bean and Jatropha for biodiesel (Agbro and Ogie, 2012). The production data for major agricultural crops output and biofuel type in Nigeria as at 2010 are presented in Table 4. It is noted that these crops are produced for food consumption and will not be available for energy production in order to avoid food shortage problems in the country. However, the production data is presented to estimate the amount of residue available for bioenergy production in the country.

Table 4 Production data for major agricultural crops output and biofuel type in Nigeria as at 2010

Agricultural resource	*Production capacity (thousand metric tons)*	*Derivable biofuel type*
Cassava	42,533	Bioethanol
Yam	33,500	Bioethanol
Millet	8,000	Bioethanol
Maize	7,677	Bioethanol
Sorghum	11,000	Bioethanol
Rice	4,600	Bioethanol
Potato	1,000	Bioethanol
Cowpea	3,368	Biodiesel
Groundnut	3,799	Biodiesel
Oil palm	1,000	Biodiesel
Sugar cane	800	Bioethanol
Sweet potato	3,000	Bioethanol
Cocoyam	2,000	Bioethanol
Cotton	602	Biodiesel
Coffee	200	Biodiesel
Cocoa	150	Biodiesel
Plantain	250	Bioethanol

Source: Simonyan and Fasina (2013)

3.2.2 Agricultural crops residues

Apart from the energy crops produced by farmers, other feedstocks for the production of bioenergy is found everywhere in the country. Among these are agricultural crops residues which are materials left on the farm after harvesting the target crops (Abila, 2012). Crop residues in Nigeria which include straws, leaves and stalk of cereals such as rice, maize/corn, sorghum, and millet, cassava stalk/peelings and cocoa pods, etc., are good sources of biofuels. There are potentials for further processing for higher energy contents. The energy potential from major agricultural crop residues in Nigeria was estimated from 2001–2006 under three different scenarios by Iye and Bilsborrow (2013) using the residue to production ratio (RPR) approach. Table 5 shows estimates of some major crop residues available in Nigeria. These residues have huge energy potential and can contribute greatly to the nation's economy, particularly those from cassava, rice and maize.

Table 5 Average annual agricultural crops residues for bioenergy production in Nigeria (2001–2006)

Crop type	*Residue type*	*Residue amount (Gg)*	*Energy (PJ)*
Maize	Stalks	5,938.01	69.83
	Cob	1,473.70	17.33
Cassava	Stalks	1,052.54	12.38
	Peelings	7,716.56	90.74
Rice	Straw	2,918.50	34.32
	Husk	806.37	9.48
Groundnut	Straw	1,369.25	16.10
	Husk	1,038.14	12.20
Yam	Peelings	6,372.83	74.93
Sorghum	Straw	5,304.86	62.39
Millet	Straw	4,571.40	53.76
Total		39,931.41	469.56

Note: Key: Gg – giga-grams (equal to 10^9 g), PJ – petajoules (equal to 10^{15} J).

Source: Akorede et al. (2017)

As shown in Table 5, cassava has the highest output of residues generated and its estimated value is about 7,716.56 Gg in terms of quantity produced between 2001 and 2006 (the conflicting interests of using cassava stalks meant for cassava cultivation as raw materials for bioenergy production can be resolved if the productivity of cassava stalks is effectively improved by applying gene modification technologies to cassava. This will invariably increase the yield of cassava per hectare). While the possible energy potential is 90.74 PJ. Cassava peelings which is a major waste generated from the processing of cassava to flour can be used with some additives to produce biogas. Nigeria has enormous potential to generate energy through this cheap and environmentally friendly source.

According to Agbro and Ogie (2012), the quality of crop residues available for energy is highly dependent upon special environment and utilisation intensity. Furthermore, seasonal availability will seriously constrain the use of residues. Estimates of crop residues availability depend largely on the effectiveness of harvest methodology, the residual quantities required to protect the soil from erosion and the density and dispersion of the residue relative to the feasibility of collecting the material.

3.2.3 Forest resources

According to the FAO (2009), residues generated from the forest products industry could be divided into two categories:

1 logging residues, generated from logging activities (these include stumps, branches, leaves, off-cuts, and sawdust

2 industrial by-products (i.e., wood processing wastes) generated by wood processing firms during the manufacture of sawn wood, plywood, particleboard, etc.

These discarded logs, bark, sawdust and shavings. Forest residues can be used to generate heat, electricity, liquid fuels and solid fuels (compressed wood such as pellets, briquettes, or charcoal briquettes (Agbro and Ogie, 2012).

About 42 t of sawdust is generated every year from 100 t of timber produced with an average of about 4.39×10^6 m^3 of log split and plywood processed annually in Nigeria (Ohunakin, 2010). The potential for sawdust generated can therefore be estimated at 1.8 million tonnes annually. This form of bioenergy is presently not exploited and yet constitutes an environmental problem.

Table 6 shows the forest resources products in Nigeria. The availability of these resources depends on the efficiency of the industry they come from. Typical residue yield from a tropical sawmill for export is between 15% and 20% of the total biomass (full tree), or 30% to 45% of the actual biomass (e.g., logs) delivered to sawmill (Simonyan and Fasina, 2013).

Table 6 Production of forest resources products in Nigeria as at 2010

Product types	*Production*	
	Volume (m^3)	*Weight (tons)*
Chemical wood pulp	-	14,000
Industrial round wood	2,279,000	-
Woodfuel	63,214,728	-
Wood charcoal	-	3,940.089
Paper board	-	18,000
Particle board	40,000	-
Plywood	56,000	-
Printing/writing paper	-	1,000
Pulp wood/round wood	39,000	-
Recovered paper	-	8,000
Sawn log + veneer logs	7,100,000	-
Sawn wood	2,000,000	-
Veneer sheets	1,000	-
Wrapping + packaging + board	-	18,000

Source: FAOSTAT (2013)

The most widely available form of forest resources in Nigeria is fuelwood (Giwa et al., 2017). The fuelwood that is being exploited in Nigeria has an energy content of 6 billion MJ. However, only 5–12% of this energy is employed for cooking purposes and other domestic applications (Oyedepo, 2012). According to Ohunakin (2010), about 80 million cubic metres, equivalent to 43.4×10^9 kg (or 43.4 million tonnes) of fuel wood with an average daily consumption ranging from 0.5–1.0 kg of dry fuel wood per person is being consumed in the country annually for cooking and domestic purposes.

3.2.4 Urban waste and other wastes

The Nigerian environment is highly polluted with enormous amounts of waste: MSW, food waste, industrial waste, and animal waste, and these are a major problem in the country (Juliet et al., 2016). Urban waste and other by-products rich in biomass can be used as feedstocks for biofuel production.

If properly processed and utilise, MSW is a potential source of biomass energy in Nigeria. MSWs are materials generated by the daily activities of humans from households, commercial and industrial sectors as a result of the concentration of population (Akorede et al., 2017). It is estimated that approximately Nigeria generates 74,428.85 tons of municipal waste daily (or approximately 27,166,530.25 ton annually) which has a potential biogas generation of 2.04 million m^3 every day (Giwa et al., 2017). However, most of these wastes are currently disposed in landfills, burned indiscriminately or discharged into sea.

Table 7 Estimates of total and characterisation of wastes generated in selected major cities in Nigeria

City	*Per capital waste generation (kg/ppd)*	*Organic wastes component (%)*	*Combustible wastes component (%)*	*Daily waste generation estimate (kg)*
Lagos	0.63	68	21	5,747,616
Kano	0.56	43	50	1,970,920
Benin	0.43	78.7	13.1	452,188
Onitsha	0.53	30.7	53.9	530,530
Ile-ife	0.46	77.9	12.6	144,164
Akure	0.54	59.5	16.2	199,638
Ado-Ekiti	0.71	60.4	25.7	371,543
Abeokuta	0.60	57.8	34.9	418,860
Ibadan	0.71	64.9	24.1	2,605,984
Makurdi	0.54	49.2	17.3	134,460
Abuja	0.57	56.4	36.4	322,107
Maiduguri	0.25	25.8	29.5	242,925
Nsukka	0.44	56.0	34.7	44,308
Port Harcourt	0.60	39.4	29.9	714,360
Ilorin	0.43	38.3	26.0	325,252
Average	0.53	53.7	28.4	-
National				74,428,848.70

Source: Federal Ministry of Environment (2011) and Suberu et al. (2013)

According to Ogwueleka (2009), the rate of MSW generation is highly influenced by population, income level, and activities. The type, amount, and concentration of household, commercial, and industrial activities determine the volume of waste generated in a municipality. Table 7 shows total and characterisation of solid waste generated in some major cities in Nigeria. From Table 7, it is very obvious that the cities produce reasonable quantities of waste with sustainable biogenic components. With increasing urbanisation and industrialisation, the annual MSW generated will continue to increase.

Therefore, biogas production from these wastes will be a profitable and viable means of reducing the menace and nuisance of urban wastes in many cities (Mohammed et al., 2014).

Another potential bioenergy source in Nigeria is animal waste. Livestock manure refers to animal garbage. The quantity of manure produced generally depends on the amount of fodder eaten, the quality of fodder, and the live weight of the animal (Duku et al., 2011). The various processes of livestock production and consumption are associated with a lot of waste generation. On a daily basis, animal dung is generated from cattle, pigs, poultry, sheep, goats, camels, horses and donkeys (Mohammed et al., 2014).

There is a great potential for energy generation from animal dung in Nigeria. Estimated daily production of 227,500 tonnes of animal waste is possible, which when converted to biogas, would yield 6.8 million m^3 of biogas daily (Aliyu et al., 2015). It is estimated that bioenergy potential of animal dung in Nigeria is 450.48 PJ (Giwa et al., 2017). The analysis carried out in 2001 gave the total number of cattle, sheep, goats, horses and pigs as well as poultry in Nigeria as 245 million. These all together produce 0.78 million tonnes of animal waste daily which is equal to 7.644×10^9 MJ with the calorific value of animal dung assumed as 9,800 MJ/tonne (Akorede et al., 2017). Table 8 shows the biogas production rates for a number of feedstock materials, majorly animal wastes.

The most recent documentation of animal waste reserve estimates in the country is given as 61 million tons per year (Dayo, 2008) and Nigeria has a potential of about 6.8 million m^3 of biogas production every day from animal waste (Odeyemi, 1993).

Table 8 Livestock population, manure production, reference energy values, their energy potentials and gas production

Resources	*Livestock population ('000)*	*Dry dung output (kg/head/day)*	*Annual dung output (ton)*	*Energy value (GJ/t)*	*Total energy potential (PJ)*	*Gas production (m^3/kg)*	*Methane content (%)*	*Retention time (days)*
Poultry	184,500	0.06	4,040,550	11.0	44.45	0.31–0.56	58–50	9–30
Pigs	7,184.35	0.80	2,097,830.2	11.0	23.08	0.49–0.75	58–61	10–15
Goats	55,145.40	0.40	8,051,228.4	14.0	112.72	-	-	-
Sheep	34,687.30	0.40	5,064,345.8	14.0	70.90	0.37–0.61	64	20
Cattle	16,400	1.80	10,774,800	18.5	199.33	0.20–0.33	-	-

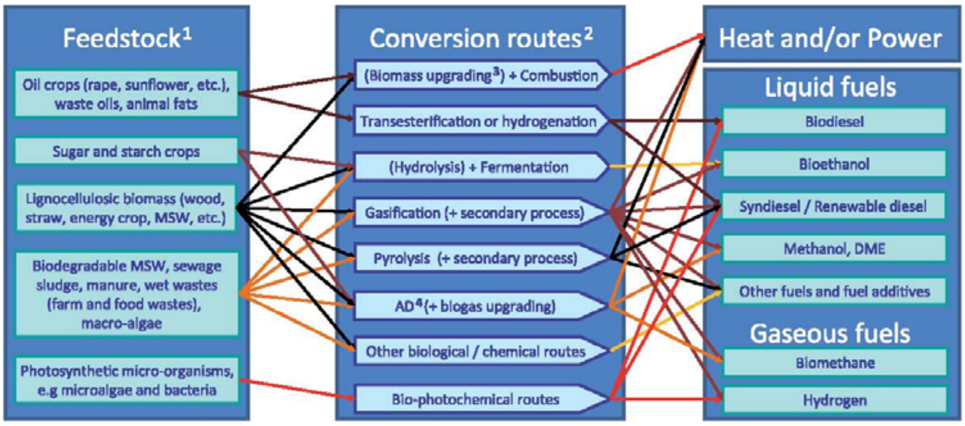
Source: Akorede et al. (2017) and FAO (2009) statistics of animal production

4 Bioenergy source conversion technologies

The conversion of biomass to energy (otherwise known as bio-energy) encompasses a wide range of different types and sources of biomass, conversion options, end-use applications and infrastructure requirements (McKendry, 2002). As presented in the previous section, biomass source can be derived from the energy crops, perennial grasses, plant residues (forest thinnings, straw, etc.), biomass wastes such as sludge from organic industrial waste and organic domestic waste, animal waste or the wastes themselves. In each case the biomass feedstock has to be harvested/collected, transported and possibly stored, before being processed into a form suitable for the chosen energy conversion technology.

A bioenergy chain, or route, consists of a series of conversion steps by which a raw biomass feedstock is transformed into a final energy product (heat, electricity, or transport biofuel) (IEA Bioenergy, 2009). Different conversion technologies have been developed that are adapted to the different physical natures and chemical compositions of feedstocks, as well as to the energy service required (heat, electricity, transport fuel). While some routes are straightforward (e.g., direct combustion of forest wood for heat production), others necessitate several pre-treatment, upgrading and conversion steps, such as those required for the production of liquid fuels that can be used in an internal combustion engine. Figure 3 shows an overview of bioenergy routes.

Figure 3 Synthetic view of the wide variety of bioenergy routes (see online version for colours)



Notes: [1]Parts of each feedstock, e.g., crop residues, could also be used in other routes.
[2]Each route also gives co-products.
[3]Biomass upgrading includes any one of the densification processes (pelletisation, pyrolysis, torrefaction, etc.).
[4]AD – anaerobic digestion.

Source: Matthew and Ralph (2017)

From Figure 3, three main classes of conversion routes can be identified:

- Thermochemical conversion, by which biomass undergoes chemical degradation induced by high temperature. The four thermochemical routes are combustion, gasification, pyrolysis, and torrefaction which differ mainly in their temperature ranges, heating rate and amount of oxygen present in the reaction.
- Physicochemical conversion is used to produce liquid fuels (biodiesel or vegetable oil) from oil crop (rapeseed, soybean, Jatropha, etc.) by oil extraction possibly followed by a transesterification process.
- Biological routes use living micro-organisms (enzymes, bacteria) to degrade the feedstock and produce liquid and gaseous fuels. The key mechanisms of this process being fermentation from sugar (sugar-cane, sugar-beet, etc.), starch (corn/maize, wheat, etc.) and lignocellulosic (grass, wood, etc.) feedstock, anaerobic digestion

(mostly from wet biomass), and the more recent bio-photochemical routes (e.g., hydrogen production using algae), which require the action of sunlight.

4.1 Biomass related technology practices in Nigeria

While several technologies for generating bioenergy heat and power already exist, for effective and efficient production of biofuels in Nigeria there is need to extend the use of most efficient technologies available today and to complete the development and deployment of a number of new technology options (Simonyan and Fasina, 2013). According to Mckendry (2002), the appropriate conversion technology for a biomass is influenced by factors such as type and quantity of biomass feedstock, the desired form of energy (end-use requirements, environmental standards, economic considerations and project specific factors).

In Nigeria, biomass conversion technologies are of different stages: some are at research level, others at demonstration stage while extremely limited numbers are at commercial stage. Biofuel production is still in its early stages of development in Nigeria. Several stakeholders including: the federal government, NNPC, universities, research institutes, private investors, and local farmers have been involved in the Nigerian Automotive Biofuel Programme. The programme which was initiated by the federal government in 2005, gave the NNPC the mandate to carry out 10% blending of biofuel with fossil fuels in the nation's refineries (Juliet et al., 2016). The biofuel produced from sugar and starchy crops are ripe for commercial or industrial scale but their feedstock are the first generation biomass and therefore face the problem of sustainability (Amigun et al., 2011).

In Nigeria, there are various biomass energy technologies for various end uses: biogas, biofuels, improved woodstoves and biomass briquetting. These are briefly discussed below.

4.1.1 Biogas and biofuel technologies

The techniques used for the conversion of organic biomass materials to solid, liquid and gaseous fuels have been in existence for many years in both the developed and developing countries. Biogas is mainly used for household heating, cooking and lighting, as well as energy production for agricultural and industrial processes. Biogas research started in Nigeria in 1982 (REMP, 2005). Since then, research activity has been sustained, but not strongly enough to make the technology attain commercial status in the country. So far, less than twenty biogas pilot projects exist in the country (biogas plants at Zaria prison in Kaduna, Ojokoro in Lagos, Mayflower School Ikene in Ogun State, and a biogas plant at Usman Danfodiyo University in Sokoto with capacity of the digesters ranges between 10 and 20 m^3) (Akinbomi et al., 2014). Under the Africa 2000 low technology biogas system, the UNDP introduced to Yobe, Jigawa and Kano States the floating drum and plastic balloon and tube types of biogas digesters. Since 2003, Kwachiri community in Kano state depended on the UNDP biogas project (using cow dung) for their daily cooking needs (REMP, 2005). Similarly the UNDP introduced biogas technology at some market abattoirs in some Northern States.

4.1.2 Woodstoves technology

The old traditional method of cooking with burning fire wood openly is very inefficient and a sources of health hazard to the users. The performance of this traditional method is only 5–10%. The fire wood consumption and the energy cooking requirements would thus be relatively high.

Three types of improved wood stove depending on the family sizes and dishes to be cooked, were designed and developed with three principal features (ECN, 2005):

1. a close heath (fire box), where combustion of the wood takes place thus protecting the fire from the effects of the wind to reduce heat lost mostly by convection and radiation
2. multi-pot design, capable of carrying out more than one pot at a time permitting heat recovery from hot gases that otherwise have gone to waste
3. a chimney to provide the necessary draft for bring in air for combustion and removing smoke from the kitchen environment, thereby making it convenient to users.

These stoves can be fabricated by local potters and artisans using available local raw materials. The fact that the technology is relatively cheap and locally obtainable has proven not to be enough incentive for complete take-off of this technology on commercial production in the country.

4.1.3 Biomass briquetting technology

In Nigeria, several machines developed for briquettes production includes a single cylinder extrusion machine that transforms rice, millet husk and sawdust to briquettes. This machine produced 13 kg of briquettes/hour at Sokoto Energy Research Centre, Usmanu Danfodio University, Sokoto, Nigeria. Another machine, sawdust briquetting Machine (Screw Press), was developed at Obafemi Awolowo University, Ile-Ife. The machine has press barrel screw shaft, bearing assembly, nozzle or die and 4 kw electric motor. It is capable of producing 10 kg/hr of sawdust, rice husk and groundnut shells briquettes with 17.8 MJ caloric value and 67.94% burning efficiency. Additionally, a simple tabletop close – end die piston process fitted with both a pressure and dial gauge has been used to produce briquette using rattan furniture waste at the University of Ibadan, Nigeria. The latest development is the briquetting machine developed by the Center for Industrial Studies (CIS) of the Abubakar Tafawa Balewa University (ATBU) Bauchi in collaboration with the Raw Material Research and Development Council (RMRDC), Abuja. This machine has four pistons and cylinders, a hopper with four feed holes table, cover and locking device and a crank arrangement as the major operating parts. This machine, using sawdust and agricultural wastes with suitable binding material, was able to produce 40 kg/hr of briquettes based on four compaction and ejection cylinders. However, only two small-scale companies exist in Nigeria, one in Ogun and Kaduna states which produce and market sawdust briquettes as all other development regarding this technology is mostly limited to research institutes, universities and other tertiary institutions in Nigeria (REMP, 2005).

The biomass technologies described above are mainly small scale technologies. There are other, larger scale biomass technologies such as cogeneration, biofuel production, pyrolysis and gasification. With the exception of biofuels, there is currently no indication of the implementation of these large scale technologies in Nigeria.

Biofuel production is still in its infancy stage of development in Nigeria. Presently, there is no commercial biofuel production from biomass energy source in the country (Juliet et al., 2016). The available ethanol plants employed the imported crude oil as feedstock. Utilising the potentials of biomass resources for commercial production of biofuel in Nigeria is a challenging issue because their upcoming biofuels project in the Nation suggests the utilisation of fruit generation biomass feedstock. Food shortage could be a problem as high-yielding energy crops such as sugar cane and cassava taken into biofuel production could result in food scarcity. There is urgent need for Nigeria to look into other low-yield biomass feed stock which are plenty in the country. Examples of these low-yield sources are Jatropha for biodiesel production, animal dung or MSW for biogases production to mention a few.

5 Barriers to BET development in Nigeria

The failure of various pilot bioenergy programmes and a low level of BET development and dissemination in Nigeria have been attributed to a number of factors among which are:

5.1 Policy and regulatory barrier

Well-formed policies are essential for the successful implementation of any technology in a country. Nigeria currently has no comprehensive renewable energy policy and in particular on BET development. There is brief mention of renewable energy technologies in the 2003 National Energy Policy, but it is not detailed enough to give proper guidance for implementing a national renewable energy programme. Hence, the development of a viable bioenergy sector in Nigeria requires a strong, supportive policy, a firm legal, regulatory and institutional framework to ensure that measures are put in place to harness the contribution of the sector to socioeconomic development while safeguarding rural livelihoods and the ecosystem.

5.2 Low level of awareness of benefits accrued from BET

The level of public and political awareness, perception and attitudes of people to new renewable energy technologies is low. To the majority of Nigerians, BET in all its forms is completely novel. There is a general lack of awareness about what options are available and what benefits can be obtained from each of these options. This is a foundational issue, as there is no way renewable energy systems can be optimally operational in the country if the prospective end users are ignorant of their potential. This situation is the result of a number of factors:

1 Inaccessibility to proper means of information dissemination. The result is that a lot of people living in rural areas find it difficult to obtain relevant information on BETs, and so are quite content to continue in their well-known traditional methods.

2 BETs are generally perceived to be used with discomfort or sacrifice rather than as providing equivalent services with less energy and cost.

5.3 Technological and technical inadequacies

These encompass a whole range of issues, including insufficient resource data; substandard product quality; inadequate research and development activity; unsolved engineering problems, ignorance of advanced production techniques, limited human and manufacturing capacities. Engineers are not well trained in renewable energy technology and thus are not conversant with the best applications and limitations of different technologies. Lack of local skilled labour to operate and maintain renewable energy equipment is another major deterrent to the widespread adoption of BET, especially in rural Nigeria. Particularly in remote areas with restricted access, on-hands maintenance is needed since frequent visits by repair and maintenance staff is difficult. Failure to provide regular maintenance of the equipment when it is required leads to their complete breakdown, thereby defeating the purpose of the initial investment.

5.4 Insufficient-funding

Inadequate financial and institutional infrastructure is a serious barrier to the rapid uptake and development of renewable energy technologies in Nigeria, particularly for the BETs such as improved wood burning stoves and biomass briquetting market development. Loan facilities to rural farmers are low. Government incentives are also inadequate. The cultivation of biofuel crops requires long-term loans and greater incentives. The poverty level in rural areas impedes farmers from getting loans, thus affecting their productivity.

5.5 Uneven distribution of biomass resource

Even though Nigeria is endowed with abundant biomass energy resources in the form of fuelwoood, crop residues, agricultural crop wastes and animal wastes, energy crops, etc., the reserves are unevenly distributed within geopolitical zone and often occur at long distances from the main energy demand centres. The uneven distribution of resources can increase transportation costs, which can amount to 25% or more of the cost of fuelwood for instance. Hence, developing biomass conversion facilities in proximity to the existing petroleum refinery infrastructure could reduce the cost of setting up new stand-alone bio-refineries. Nationally, the existing petroleum refineries seem to have adequate processing and hydrotreating facilities to convert bio-derived oils to transportation fuels.

5.6 Low conventional energy prices due to government subsidies

Low conventional energy prices hold back the development of alternative supplies even if they benefit most energy users in the shorter-term. This study does not advocate high-energy prices per se, but prices, which cover all costs. This would imply some increase in prices, which would help extend available resources, and encourage the bringing on of alternative sources and substitutes. Higher energy prices may eventually create the conditions whereby cheaper services can be delivered.

6 Prospects of BET development in Nigeria

There are enormous benefits stand to gain if BET is properly developed in Nigeria. These benefits include:

6.1 Potential environmental benefits

Potential environmental benefits to be derived from the local production and use of biomass resources and biofuel production include offsetting GHG emissions associated with burning fossil fuels, waste utilisation, and erosion control. Clearly, biomass technology may benefit the environment while at the same time it may help solve some pressing environmental problems. It has been shown that using biomass to produce energy is carbon-neutral because it releases roughly as much carbon dioxide (CO_2) as it takes in. For instance, for every MWh of power generated using biomass, approximately 1.6 tonnes of CO_2 are avoided. Biomass existing in form of solar energy kept in chemical form in plant and animals materials remains the alternative option not for power generation only but also for numerous purposes. It gives food, medicines, energy, building materials, papers, fabric, and chemicals to mention a few. Also, its contribution to the global warming is zero, a plus for the alternative form of energy. Again, biomass fuel has extremely minimal influence on the acid rain due to almost zero amount of sulphur in its content.

6.2 Socio-economic benefits

The current global interest in biomass resource and biofuel production, especially in the area of transportation fuels, presents an opportunity for both domestic and foreign investment in Nigeria as well as increased export earnings. Also, because biomass resources can be converted to liquid and gaseous fuels, electricity and process heat, they can increase access to modern forms of energy for the population. Biomass resource cultivation, harvesting, and processing could have a direct impact on rural development. Biomass and biofuels production could improve rural livelihoods by providing new income opportunities to their families. Also, development of BET in Nigeria would boost agricultural development and technological advancement, and further bring opportunities, thereby improving the quality of life of the people.

6.3 Benefits of accessibility to clean decentralised energy system

A variety of BETs that can convert renewable energy sources into more useful and convenient forms (gaseous fuels, liquid fuels, electricity, heat or shaft power) are commercially available. Their modular nature and the fact that they are more evenly distributed than conventional energy resources render BETs ideal candidates for providing decentralised energy services. Therefore, promoting BETs in Nigeria would contribute to sustainable energy development. To achieve this, appropriate institutional, legal, regulatory and fiscal framework must be put in place to address some of the barriers that are hindering their widespread dissemination in the country.

7 The way forward in achieving sustainable development through BET in Nigeria

There are numerous opportunities to explore from various types of biomass in Nigeria with an estimated 2.01 EJ (47.97 MTOE) biomass residues and wastes available annually as reported by Simonyan and Fasina (2013). For comprehensive and sustainable production and utilisation of biofuels in domestic, institutional and commercial purposes, the following recommendations should be considered:

Nigeria as a nation should tap into the unlimited opportunities in biomass sources available. It is believed that if government activities towards attaining stable, clean, dependable, affordable electricity generation via BET will be enhanced, well-structured programs and policies are to be put in place, pursued with all enthusiasm and tenacity.

- Massive awareness campaign should be undertaken on television, radio and newspapers to sensitise the populace on the use of biogas.
- Credits and financial incentives should be enhanced and expanded by governmental agencies to encourage the use of biogas. Incentives should also be given to farmer of energy crops like Jatrophta, sugar cane and rape seed.
- Domestic and industrialised development of various biogas digesters should be considered using various feedstocks.
- Laws prohibiting indiscriminate cutting of trees for fuel wood should be enacted and courageously implemented; this may induce the exploitation of other energy sources for, especially domestic activities.
- If government activities towards attaining stable, clean, dependable, affordable electricity generation via BET will be enhanced, a well-structured programs and policies are to be put in place, pursued with all enthusiasm and tenacity.
- People should be empowered and encouraged to own small to medium scale agricultural enterprises to generate cow dung, chicken droppings and other biodegradable substrates such agricultural crops wastes and energy crops.
- Government to commit resources towards research and development, capacity-building and technical support for the biofuels sector development.
- Government to establish regulatory and institutional frameworks that provide space and incentives for a wider stakeholder participation in the development of the biofuels industry involving farmers, academics, public and private sector institutions, investors and non-state actors.

8 Future research focus on the development of second generation biofuel technology in Nigeria

To solve global warming problems and ensure sustainable development of the economy, it is necessary to increase the use of renewable biomass resources (Maeda, 2007). In recent years, there have been active movements to accelerate the spread of liquid biofuels as alternative to gasoline and diesel fuel in a large number of countries, for enhancing their energy security, managing high crude oil prices and overcoming global warming problems.

Nigeria has good reasons to diversify its supply of fuels and to better exploit its natural resources, and biofuel production is an attractive option to contribute to this development (Ishola et al., 2013). To diversify the raw materials supply, research and development efforts are being made throughout the world to develop second-generation biofuel technologies. Paying attention to these moves, Nigeria should also make efforts to develop its own second-generation biofuel technologies.

Based on the above facts, the following recommendations are made as regard future research focus on the development of second generation biofuel technologies in Nigeria.

8.1 Introduction of a national biofuels strategy and a roadmap for research and development of second generation biofuel technologies

To introduce biofuels into the Nigeria transport sector, it is essential to use domestic biomass resources most effectively. To this end, the Nigerian Government is required to set both national quantitative targets and the time frame for the introduction biofuels. It should also prepare a resources strategy based on the balance between overseas and domestic biomass resources, review related policies and systems (such as the land use and agricultural policies, taxation incentives, and regulations); and prepare a roadmap for research and development of second-generation biofuel technologies in the country.

8.2 Clarification of the requirements for lands to produce energy crops and the selection of research subjects

Energy crops require a greater emphasis on increasing productivity per unit input of energy and reducing product ion costs than edible crops. Therefore, research approaches will depend significantly on the conditions, such as weather and soil, pertaining in lands selected for producing energy crops. To avoid competition between the production of energy crops and the production of foods while at the same time achieving acceptable energy crop productivity, it is likely that the lands used for energy crops will be currently uncultivated and have acidic or alkaline soils and a reasonable precipitation level, but not be extremely dry or deteriorated by salinisation. From the medium- and long-term perspectives, it is important to select as research targets technologies for producing energy crops that can be grown in the lands available for Nigerian biofuel consumption.

8.3 Cooperative multidisciplinary research in the fields of energy and life sciences required to develop second-generation biofuel technologies

Much of the worldwide research conducted on second-generation biofuel technologies is based on knowledge in the life sciences field, especially molecular biology and crop nutrition. Nigerian research in the energy field has not been conducted in cooperation with researchers in life sciences, nor effectively used the accumulated knowledge in the field of microbiology, especially fermentation, where Nigeria is considered to be strong. In the future, therefore, it is important to more actively encourage exchanges of information and researchers in these fields. In addition, it is necessary to thoroughly investigate the factors responsible for successful industry- university partnerships in research centres in the developed countries such as USA and Europe, and to establish such partnership research centres in Nigeria and concentrate research resources on them.

8.4 Development of a large-scale biofuel production strategy and inclusion of second generation biofuel feedstock

The biofuel industry in Nigeria still depends on edible foodstuff (such as maize, soya bean, sugarcane, cassava, etc.), the increasing population is a challenge, because the available food is yet to be circulated among the people. A more proactive biofuel policy is needed in order to actualise all its aims. Also, the need to include biofuel feedstock such as algae and Jatropha as second generation of biofuel in the Nigerian biofuel programme is important due to their prospects and importance on the Nigerian green economy (Elegbede and Guerrero, 2016). Moreover, range of first generation biofuels are only being produced on small scales. Currently, there is no commercial biofuel production in Nigeria. There is need for strategy for production of biofuel on commercial scale from non-edible foodstuff.

9 Conclusions

In this study, biomass resources currently available in Nigeria, and the potential to utilise them for the production of various types of biofuel has been reviewed. The review shows that a variety of biomass resources exists in the country, and that there is also an immense opportunity for their conversion to various types of biofuels using different biomass conversion technologies that are currently available. Agriculture residues, animal and poultry waste, MSW and wood residues are the major sources of biomass in the country. Total estimate of sustainable biomass potential shows that annually biomass could provide over 1,200 PJ energy, which can contribute towards the meeting of the present energy demand. Furthermore, study revealed that bio-energy reserves/potential of Nigeria stood at 13 million hectares of fuelwood, 61 million tonnes per year of animal waste, and 83 million tonnes of crop residues. Despite the fact that biomass energy resources are in abundant in Nigeria, only few projects are being implemented by the government, research centres and private organisations to develop BETs. In this regard, to improve and develop BET in Nigeria, the government should be more conscientious for overcoming technical, political and commercial barriers, monitoring and fast implementation of projects, providing funds, reducing cost, raising mass awareness and research activities.

References

Abila, N. (2012) 'Biofuels development and adoption in Nigeria: synthesis of drivers, incentives and enablers', *Energy Policy*, Vol. 43, pp.387–395.

Adaramola, M.S., Paul, S.S. and Oyedepo, S.O. (2011) 'Assessment of electricity generation and energy cost of wind energy conversion systems in north-central Nigeria', *Energy Conversion and Management*, Vol. 52, pp.3363–3368.

Agba, A.M., Ushie, M.E., Abam, F.I., Agba, M.S. and Okoro, J. (2010) 'Developing the biofuel industry for effective rural transformation', *European Journal of Scientific Research*, Vol. 40, pp.441–449.

Agbro, E.B. and Ogie, N.A. (2012) 'A comprehensive review of biomass resources and biofuel production potential in Nigeria', *Research Journal in Engineering and Applied Sciences*, Vol. 1, No. 3, pp.149–155.

Akinbami, J.F.K. (2001) 'Renewable energy resources and technologies in Nigeria: present situation, future prospects and policy framework', *Mitigation and Adaptation Strategies for Global Change*, Vol. 6, pp.155–181, Kluwer Academic Publishers, Netherlands.

Akinbomi, J., Brandberg, T., Sanni, S.A. and Taherzadeh, M.J. (2014) 'development and dissemination strategies for accelerating biogas production in Nigeria', *BioResources*, Vol. 9, No. 3, pp.5707–5737.

Akorede, M.F., Ibrahim, O., Amuda, S.A., Otuoze, A.O. and Olufeagba, B.J. (2017) 'Current status and outlook of renewable energy development in Nigeria', *Nigerian Journal of Technology (NIJOTECH)*, Vol. 36, No. 1, pp.196–212.

Aliyu, A.S., Dada, J.O. and Adam, I.K. (2015) 'Current status and future prospects of renewable energy in Nigeria', *Renewable and Sustainable Energy Reviews*, Vol. 48, pp.336–346.

Amasuomo, E. and Ojukonsin, T. (2015) 'Exploring the potential of organic waste as a source of methane gas for electricity generation in Nigeria', *Journal of Management and Sustainability*, Vol. 5, No. 3, pp.99–106.

Amigun, B., Musango, J.K. and Stafford, W. (2011) 'Biofuels and sustainability in Africa', *Renewable and Sustainable Energy Reviews*, Vol. 15, pp.1360–1372.

Anowor, O.F., Achukwu, I.I. and Ezekwem, O.S. (2014) 'Sustainable sources of energy and the expected benefits to Nigerian economy', *International Journal of Sustainable Energy and Environmental Research*, Vol. 3, No. 2, pp.110–120.

Audu, T.O.K. and Aluyor, E.O. (2012) 'Potential of bioenergy and biofuels technology development in Nigeria', *Petroleum Technological Development Journal*, Vol. 1, pp.1–7.

Balogun, B.O. (2015) 'Potentials for sustainable commercial biofuels production in Nigeria', *STECH*, Vol. 4, No. 2, pp.25–40.

Chindo, S., Abdulrahim, A., Waziri, S.I., Huong, W.M. and Ahmad, A.A. (2014) 'Energy consumption, CO_2 emissions and GDP in Nigeria', *GeoJournal*, Vol. 80, pp.315–322 [online] http://dx.doi.org/10.1007/s10708-014-9558-6.

Dawit, D.G. (2012) 'Assessment of biomass fuel resource potential and utilization in Ethiopia: sourcing strategies for renewable energies', *International Journal of Renewable Energy Research*, Vol. 2, No. 1, pp.131–139.

Dayo, F.B. (2008) *Clean Energy Investment in Nigeria, The Domestic Context*, A Case Study for International Institute for Sustainable Development (IISN), Winnipeg, Manitoba Canada.

Duku, M.H., Gu, S. and Hagan, E.B. (2011) 'A comprehensive review of biomass resources and biofuels potential in Ghana', *Renewable and Sustainable Energy Reviews*, Vol. 15, pp.404–415.

Elegbede, I. and Guerrero, C. (2016) 'Algae biofuel in the Nigerian energy context', *Environmental and Climate Technologies*, pp.44–60, De Gruyter, DOI: 10.1515/rtuect-2016-0005.

Emodi, N.V. and Yusuf, S.D. (2015) 'Improving electricity access in Nigeria: obstacles and the way forward', *International Journal of Energy Economics and Policy*, Vol. 5, No. 1, pp.335–351.

Energy Commission of Nigeria (ECN) (2005) *Renewable Energy Master Plan*, Final Draft Report, Federal Republic of Nigeria, Abuja, Nigeria, pp.135–177.

FAO (2009) *The State of Food and Agriculture*, pp.150–180, FAO United Nation, Rome [online] http://www.fao.org/docrep/012/i0680e/i0680e.pdf (accessed 19 June 2018).

FAOSTAT (2013) *Food and Agriculture Organization of the United Nations*, Rome [online] www.fao.org/docrep/018/i3107e/i3107e.PDF (accessed 20 October 2018).

Federal Ministry of Environment (FME) (2011) *Renewable Energy and Pollution Control Department*, Waste Statistics 2011, FME National HQ, Greenhouse-Abuja [online] http://www.environment.gov.ng/downloads/COP22%20REPORT%2022%20NOV%202016.pdf (accessed 20 May 2018).

Garba, N.A. and Umar Zangina, U. (2015) 'Rice straw & husk as potential sources for mini-grid rural electricity in Nigeria', *International Journal of Applied Sciences and Engineering Research*, Vol. 4, No. 4, pp.523–530.

Girard, P. and Fallot, G. (2006) 'Review of existing and emerging technologies for the production of biofuels in developing countries', *Energy for Sustainable Development*, Vol. 10, No. 2, pp.92–108.

Giwa, A., Alabi, A., Yusuf, A. and Olukan, T. (2017) 'A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria', *Renewable and Sustainable Energy Reviews*, Vol. 69, pp.620–641.

Govinda, R.T. and Ashish, S. (2010) *Policy Research Working Paper on Biofuels – Markets, Targets and Impacts*, The World Bank Development Research Group Environment and Energy Team, Lisbon, Portugal, pp.1–49 [online] http://econ.worldbank.org (accessed 19 June 2018).

GRFA (2013) *Interactive World Biofuel Maps*, Global Renewable Fuel Alliance.

IEA Bioenergy (2009) *Bioenergy – a Sustainable and Reliable Energy Source: a Review of Status and Prospects*, pp.1–108, Energy Research Centre of the Netherlands (ECN), E4tech, Chalmers University of Technology, and the Copernicus Institute of the University of Utrecht, UK.

IRENA (2014) *Renewable Energy Map (Remap) 2030 Global Bioenergy Supply and Demand Projections*, Japan, pp.15–18 [online] http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/IRENA_REmap_2030_Biomass_paper_2014.pdf (accessed 20 April 2018).

Ishola, M.M., Brandberg, T., Sanni, S.A. and Taherzadeh, M.J. (2013) 'Biofuels in Nigeria: a critical and strategic evaluation', *Renewable Energy*, Vol. 55, pp.554–560.

Iwayemi, A. (2008) 'Nigeria's dual energy problems: policy issues and challenges', *International Association for Energy Economics*, Vol. 53, pp.17–21.

Iye, E.L. and Bilsborrow, P.E. (2013) 'Assessment of the availability of agricultural residues on a zonal basis for medium-to large-scale bioenergy production in Nigeria', *Biomass and Bioenergy*, Vol. 48, pp.66–74.

Juliet, B., Vasilije, M. and Philiph, L. (2016) 'Biomass resources and biofuels potential for the production of transport fuels in Nigeria', *Renewable and Sustainable Review*, Vol. 63, pp.172–192.

Maeda, S. (2007) 'Research and development trends in energy crops and biofuel conversion technologies', *Science and Technology Trends, Quarterly Review*, No. 25, pp.50–73.

Maijama'a, D., Maijama'a, L. and Umar, M. (2015) 'Renewable sources of energy for economic development in Nigeria', *International Journal of Sustainable Energy and Environmental Research*, Vol. 4, No. 2, pp.49–63.

Mamun, M.R.A., Kabir, M.S., Alam, M.M. and Islam, M.M. (2009) 'Utilization pattern of biomass for rural energy supply in Bangladesh', *International Journal on Sustainability & Crop Prod.*, Vol. 4, No. 1, pp.61–70.

Matthew, O. and Ralph, R. (2017) *Bioenergy for Sustainable Energy Access in Africa*, pp.1–165, LTS International Limited and E4tech, UK [online] http://www.e4tech.com/2018/report/ (accessed 12 June 2018).

McKendry, P. (2002) 'Energy production from biomass (part 2): conversion technologies', *Bioresource Technology*, Vol. 83, pp.47–54.

Mohamad, M. and Anuge, J. (2016) *The Challenge for Future Sustainable Development in Power Sector*, pp.1–17, World Association of Sustainable Development (WASD), UK [online] http://usir.salford.ac.uk/37674/7/Mostafa%20Mohamad.pdf (accessed 9 June 2016).

Mohammed, Y.S., Mustafa, M.W., Bashir, N., Ogundola, M.A. and Umar, U. (2014) 'Sustainable potential of bioenergy resources for distributed power generation development in Nigeria', *Renewable and Sustainable Energy Reviews*, Vol. 34, pp.361–370.

Nwaokocha, C.N. and Giwa, S.O. (2016) 'Investigation of bio-waste as alternative fuel for cooking', in *3rd International Conference On African Development Issues (CU-ICADI)*, Covenant University, Ota, Nigeria, 9–11 May 2016, pp.1–5 [online] http://cu-icadi.covenantuniversity.edu.ng (accessed 15 May 2017).

Odeyemi, O. (1993) 'Resource assessment for biogas production in Nigeria', *Nigerian Journal of Microbiology*, Vol. 3, pp.59–64.

OECD (2008) *Biofuels Support Policies: an Economic Assessment*, Organization for Economic Cooperation and Development (OECD), Paris [online] http://www.oecd.org/tad/agricultural-rade/biofuelsupportpoliciesaneconomicassessment.htm (accessed 23 May 2018).

OECD/IEA (2010) *Sustainable Production of Second-Generation Biofuels, Potential and Perspectives in Major Economies and Developing Countries, Information Paper*, International Energy Agency, 75739 Paris Cedex 15, France [online] http://www.iea.org/papers/2010/second_generation_biofuels.pdf (accessed 12 May 2018).

OECD-FAO (2008) *Agricultural Outlook 2008–2017*, Organization for Economic Cooperation and Development-Food and Agriculture Organization of the United Nations (OECD-FAO), Paris [online] http://www.oecd.org/trade/agricultural-trade/40715381.pdf (accessed 6 March 2018).

Ogbonna, I.O., Moheimani, N.R. and Ogbonna, J.C. (2015) 'Potentials of microalgae biodiesel production in Nigeria', *Nigerian Journal of Biotechnology*, Vol. 29, pp.44–55.

Ogwueleka, T.C. (2009) 'Municipal solid waste characteristics and management in Nigeria', *Iran Journal of Environmental Health Science Engineering*, Vol. 6, pp.173–180 [online] http://dx.doi.org/10.1016/j.wasman.2007.09.039.

Ohunakin, S.O. (2010) 'Energy utilisation and renewable energy sources in Nigeria', *Journal of Engineering and Applied Sciences*, Vol. 5, No. 2, pp.171–177.

Olaoye, J.O. (2011) 'An analysis of the environmental impacts of energy crops in Nigeria towards environmental sustainability', in Ogunlela, A.O. (Ed.): *Tillage for Agricultural Productivity and Environmental Sustainability, Proceedings of Nigerian Branch of International Soil Tillage Research Organization*, University of Ilorin, Kwara State, Nigeria, pp.204–212 [online] https://searchworks.stanford.edu/view/9598232 (accessed 18 April 2017).

Onochie, U.P., Obanor, A. and Aliu, S.A. (2015) 'Electricity crisis in Nigeria: the way forward', *American Journal of Renewable and Sustainable Energy*, Vol. 1, No. 4, pp.180–186.

Oyebanji, J.A., Okekunle, P.O., Lasode, O.A. and Oyedepo, S.O. (2017) 'Chemical composition of bio-oils produced by fast pyrolysis of two energy biomass', *Biofuels*, pp.1–10, DOI: 10.1080/17597269.2017.1284473.

Oyedepo, S.O. (2012) 'On energy for sustainable development in Nigeria', *Renewable Sustainable Energy Review*, Vol. 16, pp.2583–2598.

Ozoegwu, C.G., Ezeb, C., Onwosi, C.O., Mgbemene, C.A. and Ozor, P.A. (2017) 'Biomass and bioenergy potential of cassava waste in Nigeria: estimations based partly on rural-level garri processing case studies', *Renewable and Sustainable Energy Reviews*, Vol. 72, pp.625–638.

Renewable Energy Master Plan (REMP) (2005) *Final Draft Report*, pp.165–177, Federal Republic of Nigeria, Abuja, Nigeria.

Sambo, A.S. (2005) 'Renewable energy for rural development, the Nigeria perspective', *ISESCO Science and Technology Vision*, Vol. 1, pp.12–22.

Sambo, A.S. (2009) 'Strategic developments in renewable energy in Nigeria', *International Association for Energy Economics*, 3rd Quarters, pp.15–19.

Shikida, P.F.A., Finco, A., Cardoso, B.F., Galante, V.A.G., Rahmeier, D., Bentivoglio, D. and Rasetti, M. (2014) 'A comparison between ethanol and biodiesel production: the Brazilian and European experiences', in Domingos Padula, A. et al. (Eds.): *Liquid Biofuels: Emergence, Development and Prospects*, Lecture Notes in Energy 27, Springer-Verlag, London.

Simonyan, K.J. and Fasina, O. (2013) 'Biomass resources and bioenergy potentials in Nigeria', *African Journal of Agricultural Research*, Vol. 8, No. 40, pp.4975–4989.

Singh, K.J. and Sooch, S.S. (2004) 'Comparative study of economics of different models of family size biogas plants for state of Punjab, India', *Energy Conversion & Management*, Vol. 45, pp.1329–1341.

Suberu, M.Y., Bashir, N. and Mustafa, M.W. (2013) 'Biogenic waste methane emissions and methane optimization for bioelectricity in Nigeria', *Renewable Sustainable Energy Review*, Vol. 25, pp.643–654 [online] http://dx.doi.org/10.1016/j.rser.2013.05.017.

World Bioenergy Association (WBA) (2014) *Global Bioenergy Statistics*, pp.20–40, World Bioenergy Association, Sweden [online] https://worldbioenergy.org/uploads/WBA%20Global%20Bioenergy%20Statistics%202014.pdf (accessed 3 March 2017).

World Energy Council (WEC) (2016) *World Energy Resources, Bioenergy 2016*, pp.40–62, World Energy Council, UK [online] https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Bioenergy_2016.pdf (accessed 13 February 2018).