Electricity and Biofuel Production from Biomass in Nigeria: Prospects, Challenges and Way Forward

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Abstract Nigeria currently produces less energy required for uninterrupted electricity supply. This situation has led to an energy crisis that is adversely affecting every sector of the economy. An exploration of energy contributions from different sources could help address the energy crisis in Nigeria. This paper aims at promoting the commercial availability of electricity from biomass in Nigeria. The biomass potentials identified include conventional crops, agricultural residues, tertiary residues; forest residues; energy crops; grasses and aquatic weeds including algae. Conversion of biomass to bioenergy can be achieved through anaerobic digestion, gasification, pyrolysis or esterification. Although the prospects are bright, challenges facing bioenergy in Nigeria, include inadequate information on feedstock; uncomprehensive research and development capacity; poor policy formulation and implementation; poor regulatory framework, poor investment climate and poor access to technology. An integrated approach is recommended to include the establishment of Nigerian Biofuel Corporation under a Public-Private Partnership (PPP) arrangement and a Nigerian Network on Bioenergy.

Keywords: Biomass potential, bioenergy, clean energy, technology, energy mix

1. Introduction

Although Nigeria is the largest economy in sub-Saharan Africa, the shortcoming in the power sector stifles growth in her economy. Nigeria lacks sufficient electricity to power a modern economy, and this deficiency is a fundamental barrier to her prosperity. No economy can make the transition from poverty and low productivity to higher incomes and global competitiveness without high-energy systems. Unfortunately, the electricity deficit reflects the current economic, social, and public infrastructure development in the country. This deficit hinders the progress of current and future generations of Nigerians and therefore adversely affects sustainability. Nigeria is blessed with oil, gas, hydro, and solar resources, with the potential to generate up to 12,522 megawatts (MW) of electric power [1]. Currently, about 4000 MW of electricity mostly from hydropower and thermal stations is being distributed, which is insufficient to meet the demands of Nigerians. The demand for energy in Nigeria is about 35,000 MW, with an estimate that a person consumes 136 kWh. Therefore, there is about 30,000 MW deficits in the demanded energy [2]. This imbalance leads to the poor, and irregular electricity supply experienced all over the country. Although Nigeria generates energy from diverse sources - conventional and renewables, yet, about 85 million out of over 200 million do not have access to electricity [3]. Some energy sources, such as bioenergy, solar, wind, and other renewables, did not contribute significantly to the grid for the year 2019 [4]. As a result, the reliability of the available electricity supply is unsatisfactory even for those with access to electricity. This deficit leads to the use of stand-alone generators (found...
in most homes, offices, factories, and industries) as alternatives to grid electricity. These stand-alone generators create pollution in our environment, with a potential health challenge, and they are expensive to run in terms of the initial cost, maintenance cost and cost of diesel. In an attempt to improve power generation in Nigeria, the commercialization and privatization of electricity plants gave an option for better management. Unfortunately, such privatization influenced the increase in tariffs. In recent times, there have been increases in electricity and petrol prices, even when the country is battling with COVID-19 [5].

According to SESN [2], renewable energy such as geothermal and tidal energy are under-exploited for generating electricity. It implies that the contribution of other renewable resources in Nigeria is insignificant except for hydro, solar, and livestock manure, buttressing the fact that renewable energy in Nigeria is under-exploited. For instance, the solar systems in Nigeria are limited to drying crops, chick brooding, lighting and pumping water, mostly in rural areas as a few stand-alone, off-grid projects. It must be noted, however, that some organizations are currently implementing large scale solar farms in different parts of the country. The application of a solar water-heating system that is important in most factories is underutilized based on the lack of sensitization [2]. Biogas can be used to generate electricity that contributes to the grid system, but the 586 m$^3$ of biogas plants installed in Nigeria are for cooking and heating purposes. The generation of bioethanol capacity, made from cassava, is about 15.3 L per annum. Bioethanol from starchy foods compete with food supply as cassava is a primary food in diverse forms to families in all part of the country. The use of conventional food for fuel is detrimental to food availability as Nigeria is enlisted among the Hunger affected countries.

Considering our agricultural prospect in crop generation, the residues (both field and process-based) are material feedstock in the production of biofuel [6, 7]. Thus far, biomass residues from crops have not been exploited extensively as feedstock to generate modern biofuels in Nigeria, especially at a low-medium scale. These limitations, however, prevent the realization of energy potentials and utility. According to the report from Renewable Energy Master Plan [4], there is need to increase the total electricity generated to 23% (in 2025) then to 36% (in 2030) from 13% supplied in 2015. There is a necessity to assess bioenergy feedstock as well as revisiting the challenges hindering the adoption of bioenergy in Nigeria [8]. Electricity from renewable energy, such as bioenergy must be included to a level that accounts for 10% of total energy consumption by 2025 in Nigeria. This requires a comprehensive review of the system to identify and proffer solutions. This paper is a contribution to current efforts at promoting the commercial availability and use of biofuel for electricity generation in Nigeria.

2. Clean Energy Solution Prospects in Nigeria

Energy drives all aspects of the economy of any nation. Modern agriculture, transportation, manufacturing, infrastructure, education, information and communications, recreation, etc., all depend on a reliable and steady supply of one form of energy or the other. The cleanest form of energy is electricity. However, the production of electricity and other clean energy solutions may require the use of energy sources and technologies that affect the environment negatively through the emission of toxic substances that are discharged into the atmosphere or waterways. Before now, most electrical energy is produced using conventional energy sources in form of hydrocarbons (petrol, gas) which are used in thermal plants to convert heat to electricity. These sources can deplete with time and so are not sustainable energy solutions. They also pollute the environment. These issues led to the search for alternative energy
systems - renewable energy sources. The renewable energy sources that have great potentials in being converted to electricity in Nigeria include solar, wind, hydrogen or fuel cell, tidal, hydro, and biomass. A clean energy solution is a total package of energy from production to usage that does not pollute the environment and is sustainable in the sense that it is also renewable [8]. Energy can be produced from biomass in form of liquid and solid fuels such as biodiesel, ethanol, methanol, biogas, briquettes, wood pellets, etc. This type of energy is referred to as bioenergy or biofuel, and the source is renewable if realistically replaced. The traditional biomass abundantly used in Nigeria but produced in an unsustainable way. The use of biomass in its crude form is limited to for cooking, and firing purposes gives very low energy efficiencies [9].

3. Bioenergy and Biofuel
Biomass is an organic material from plant or animal used for energy production (as electricity or heat), or in various industrial processes as the raw material for a range of products. Examples include energy crops, agricultural and forestry products, and residues, manure (from animal and humans), and microbial biomass. Bioenergy is derived from bio-resources as the stored chemical energy produced directly or indirectly from the sun. Bioenergy is generated from biomass or biofuel such as fuelwood, charcoal, bioethanol, biodiesel, biogas (methane), or bio-hydrogen. Over the years, as population, pollution, and technology advance, the demand for energy increases. The value chain for production of electricity from biomass includes sourcing for the feedstock, conversion technology, handling and storage, distribution and use. The routes to the production of heat, electricity or liquid biofuel using biomass are illustrated in Figure 1.

3.1 Biofuel Feedstock
Conventional crops are starch-rich foods or staple foods [10]. Their use competes with edible food, which may lead to cost inflation because the need for fuel is relatively on the same pedestal as energy demand. Such food versus fuel competition is not safe for Nigeria, considering its growing population. However, non-food options are sustainable for bioenergy generation. Agricultural residues include residues generated after harvest and during crop processing. They constitute pollution at the refuse dump because they are highly underutilized [11]. They are less competitive with food, cheaper, and abundant. Also, there is no competition with marginal/forest land, preserving the biodiversity. There is a variation in the chemical composition of residues for conversion into energy rather than being burnt to pollute the environment, causing additional disrupt on soil structure and nutrients. Tertiary crop residues are generated from waste products from plant materials [12]. Tertiary crop residues may be classified into municipal solid waste or municipal liquid waste, commonly generated in urban areas. Urbanization and industrialization in a given community increase the generation and availability of such wastes. Forest residues from harvesting logs and its processing of the woods are converted into modern fuel. Although large biomass is available in Nigeria, it is consumed traditionally, for heating and cooking [13]. Since biofuel holds the potential of contributing to grid electricity, biofuel can contribute to solving energy challenges in Nigeria. Unfortunately, the policy that facilitates the use of modern biomass for electrification or as a transport fuel (first as a blend of biofuel-fossil) is yet to be established as a law. Such delay may be due to the inconclusive strategies and assessment.
3.2. Other Plants for Energy

Energy crops are referred to as non-edible crops cultivated for energy production. Examples include Jatropha curcas, Miscanthus, Poplar, and Eucalyptus [14]. These crops require fewer crop management practices [15]. Although the oil from Jatropha is directly combustible, it competes with land for agriculture (for cultivation and husbandry) and threatens bio-diversity upon land expansion by the use of arable lands and forests. Grasses are rich in fiber content that is convertible to cellulosic ethanol via anaerobic digestion. They are abundant and available throughout the year with limited use for fodder, hay, soil preservation from soil erosion, and renewal of soil nutrients. Grasses that can be used to produce bioenergy include Typha grass, switch grass, etc. However, regarding cellulosic ethanol, grasses have not been harnessed extensively in Nigeria [14]. The coastal regions in Nigeria have fast-growing aquatic weeds. Bracken fern, water lettuce, and hyacinth are aquatic weeds with a potential convertible to biogas upon bio-digestion [13]. Algae are microforms of aquatic weeds and can be used to produce biodiesel, biobutanol or biogas in the same way as other biomass [16, 17].

3.3 Bioenergy Conversion Technologies

These conversion techniques process biomass resources into useful biofuel for electricity generation, heat and transport fuel (Fig. 1). Anaerobic digestion can produce cellulosic ethanol and biogas. This process requires enzymes, micro-organisms, moderate temperatures, and water. This method employs the use of enzymes for the hydrolysis of lignocellulose content, which is before the fermentation of hydrolyzed sugars into cellulosic ethanol. Also, micro-organisms ferment residues to produce biogas [18]. Gasification conversion technology requires the use of high temperatures to generate gases from solids. The composition of the gases produced varies but includes CO, CO$_2$, CH$_4$, and some hydrocarbons. Such gases are referred to as syngas [13]. Pyrolysis is the thermal decomposition of biomass at temperature range 350-550°C. It generates several products (solid, liquid, and gas) from the feedstock in the absence of oxygen. Esterification process produces biodiesel in the presence of a suitable catalyst, bio-oil, and alcohol solvent under appropriate temperature and pressure [13].

![Figure 1: Bioenergy potential in biomass](image)

3.4 Challenges

Although the potential for producing bioenergy from biomass is huge in Nigeria, the actual production is still very low. This is as a result of several challenges which need to be
addressed. These include: poor information on feedstock, inadequate research and development, poor policy formulation and implementation; poor regulatory framework; poor investment climate; and poor access to technology.

3.4.1 Poor Information on Feedstock
One of the strategies for developing biofuel plants includes assessing the potential feedstock, data acquisition, and establishing a database on feedstock for biofuel production. Also, the database on non-edible oil for biodiesel is essential. The feedstock assessment includes their present and future availability. Besides, a detailed analysis of the technical, socio-economic, and sustainable assessment and integrated methodology is required for the feasibility of establishing a biofuel plant [19, 20]. Also, the approach to such analysis should be encompassing, i.e., resource-driven, demand-driven, and integrated (Figure 2). Since these crops are seasonal, there is a need to identify other suitable feedstock that can suffice in the absence of others. The information from the assessment guides the selecting feedstock, as well as other investment decisions, thereby avoiding complexity.

![Figure 2: Integrated assessment towards sustainable bioenergy from biomass](image)

3.4.2 Inadequate and Un-coordinated Research and Development
There is a need for a reliable and certified database for each potential feedstock. However, a study on the detailed characterization should include proximate, compositional, and thermal analysis required for building such a database. The information from the research will define the feedstock suitability as well as its potentials for other applications. There is also a need for research into the modification of the crops to yield more oil. Besides, research targeted at developing plants with indigenous materials is essential in minimizing the cost of importing and installing the new technology. One other major challenge with Research and Development is the near absence of some of the sophisticated equipment required for characterization of the feedstock, oils from biomass and the biofuels produced.

3.4.3 Poor Policy Formulation and Implementation
The inconsistency of policies over time has hampered the gradual incorporation of bioenergy as many policies designed to solve the energy crisis never made it into bill/law. It, therefore,
reveals how much Nigeria has neglected potential solutions to solving the energy problem [21]. Currently, a new policy of dual fuel-powered vehicles is in place but has not been fully implemented. There are also no incentives for industries that want to engage in biofuel production or use.

3.4.4 Poor Regulatory Framework
There appears to be no special regulatory framework for biofuel/bioenergy production, distribution and use. This is within the bigger regulatory framework of the Department of Petroleum Resources.

3.4.5 Poor Investment Climate
For bioenergy to contribute significantly to Nigeria’s energy mix, there is a need for serious syndicated investment promotion with incentives from the government. So far, this has not happened successfully in Nigeria.

3.4.6 Poor Access to Technology
Bioenergy conversion and handling require technical expertise and specialized equipment for the production and maintenance of plants. Nigeria is indeed far behind in technology. High technological know-how is crucial for sustained biofuel production to meet standards and the competitive biofuel market and engines, as well as to solve the energy challenge in Nigeria.

4. Unlocking the Future of Biofuel in Nigeria

4.1 An Integrated Approach is Imperative
Unlocking the future of biofuel in Nigeria lies in the appropriate implementation of an integrated system as illustrated in Figure 3. However, the role of sensitization cannot be over-emphasized. Information flow cuts across the government through the farmers, investors, research, and financial institution to the end-user.

The role of the government includes sensitizing the farmers via the farmers’ associations to improve harvest logistic as well as investing in equipment for residue collection. Also, an infrastructure for its storage is needed. This process of residue collection and storage will help in acquiring data on the number of residues generated (in practice, not an estimate) and the amount supplied in a given location. The awareness created on the importance of residues and the logistics involved in its collection and storage creates a market. However, an incentive demand will reduce residue burning and enhance its marketability. This market for residues will yield data on demand and supply of residues, and the cost, taking into account transportation and other logistics. Such sensitization will consequently improve farming practices and management as well as crop production that generates residues.

The government can provide a suitable platform for business through policy implementation for biofuel generation that attracts investors within and outside Nigeria [22, 23]. Although organizations such as Energy Commission of Nigeria (ECN) and Nigerian National Petroleum Corporation (NNPC) are currently driving the process, there is need to create a commercial, large scale Bioenergy Corporation under a Public-Private Partnership (PPP) arrangement which will coordinate and implement the activities described in Fig. 3. It is also suggested that a Nigerian Network for Bioenergy should be created to bring all stakeholders in Biomass conversion to energy together.
4.2 Current Efforts at African University of Science and Technology (AUST)

Research and development work is in progress at African University of Science and Technology (AUST), towards valorization of biomass for different applications including synthesizing earth-based composites building materials for roofing sheets, particleboard, ceiling boards, bricks; natural fibre reinforced polymers for automobile applications and bioenergy. The work going on in the area of bioenergy include:

- Crop residue assessment towards modern bioenergy
- Biodiesel from oil-bearing ants and insects
- Biodiesel from non-edible seeds
- Switchgrass and its genetically modified form for bioethanol production
- Bioethanol from non-edible fruits
- Activated carbon generated from these residues and their energy storage capacity in batteries
- Briquettes and pellets from these residues for biofuel production
- Electricity production from biomass.

5. Conclusions

In this discussion, we have shown the need to intensify efforts towards the production of electricity from biomass in Nigeria. Conversion of biomass to bioenergy can be achieved through established technologies. Although the prospects are bright, challenges facing bioenergy in Nigeria include poor information on feedstock; inadequate research and development capacity; poor policy formulation and implementation; poor regulatory framework, poor investment climate and poor access to technology. An integrated approach is recommended to solve the problems identified. This approach includes the establishment of Nigerian Biofuel Corporation under a Public-Private Partnership (PPP) arrangement, and the establishment of a Nigerian Network on Bioenergy.

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