A Review on the Renewable Energy from Agricultural and Forest Residues in Nigeria

Abel O. Olorunnisola, Ayodele Richards, and Temidayo E. Omoniyi

[1]Professor at the Department of Wood Products Engineering
[2]PhD Student at the Department of Wood Products Engineering
[3]Department of Wood Products Engineering
[1,2,3]Faculty of Technology, University of Ibadan, Ibadan, Nigeria
Email: [1]abelolorunnisola@yahoo.com

***Abstract*—** Nigeria is blessed with abundant natural resources among them are residues from agricultural and forest sources. Since these residues are usually dumped in landfills as waste, constituting environmental and waste disposal problems, the need to utilise them is necessary in achieving the seventh and ninth targets of the Sustainable Development Goals (SDGs) of the United Nations. One of the avenues where agricultural and forest residues can be utilised is through biomass technology. Therefore, this paper assessed the potential conversion of these residues into useful and sustainable electricity generation in Nigeria. In addition, the paper gathers information from a pool of relevant reports on the current state of Nigeria's power sector and the domestication of some small-scale biomass power plants across the country. In this review paper, it was found that Nigeria is one of the biggest economic power in Africa and has the potential to generate electricity and other bioenergy products from the present stock of biomass available in the country, thereby making the country self-sufficient in the provision of power supply and fuel production.

***Keywords*—** Agricultural residue, Biomass, Waste conversion technology, Renewable energy.

I. INTRODUCTION

NIGERIA is rich in abundant natural resources enough to make the country an emerging economic power in the world. Currently, the country boast of having the highest GDP of $442.98 billion in Africa as at 2020 [27], therefore, in this post COVID-19 pandemic era, Nigerians can rely-on the applications and benefits attached to renewable energy in their daily lives. The renewable energy resources are becoming a trend globally in recent years. Renewable energy has been known to solve world's energy problem in a sustainable manner. Nigeria can comfortably solve the current energy crisis through the development of Biomass technology. The term biomass refers to organic materials that can serve as a source of sustainable and renewable energy. One area in biomass applications that have not been studied sufficiently in Nigeria is the application of residues from agricultural and forest sources. Currently, the country has about 21 million ha of forest cover with a sizeable chunk of residues being generated from forest logging and wood processing industries. Meanwhile, agricultural land covers about 69,123,450 ha [7-8], with a potential to generate between 697.15 Terajoule (TJ is equal to 1012 Joules) and 1.09 Exajoule (EJ is equal to 1018 Joules) from agricultural residues alone, based on 2010 and 2020 data respectively [16, 36].

With the right technological transfer to Nigeria (i.e. on biomass conversion technologies BCT), the country can conveniently channel the large reserves of residues from agricultural and forest sources into electricity generation and biofuel production. By so doing, greenhouse gases (GHG) will be reduced, waste disposal load will decline, jobs will be created, and value added products will be achieved from agricultural and forest residues generated scheme. Hence, the sixth, seventh and ninth sustainable goals that borders on improving clean sanitation, affordable and clean energy provision and the development of innovative products will be made possible, especially in rural areas of the country.

II. METHODOLOGY

This paper focuses on biomass conversion of forest and agriculture resources into useful electricity supply in Nigeria. The paper involved an extensive review on current literatures from credible journal articles, information from primary and secondary data and electronic sources. These data from primary and secondary data were obtained from internet search engines like google, google scholar, researchgate.net, and snow balling of relevant articles references. Some of the documents obtained were from Federal Ministry of Environment of Nigeria, United States Energy Information Administration, Food and Agriculture Organization of the United Nations, International Energy Agency and other international organisations. Given the current energy crisis in the country, particularly power supply, this paper attempts to outline possible alternatives using biomass renewable energy, especially for rural communities.

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III. FOREST RESOURCES

A. Forest Biomass

According to the latest data, report has it that Nigeria has forest cover that span 21,626,950 ha [8]. Even though, the forest cover represents less than 8% of the land area of the country, it is still one of the largest in West Africa region. The forest resources available in form of biomass has the potential for bioenergy and biofuel production in the country. Forest biomass, especially woody ones, is one of the most important sources of renewable energy globally [19-21, 26]. Therefore, according to [26], [15], and [12], the conversion of forest based biomass into bioenergy, globally, was estimated to be 30 Exajoule (EJ-1018 Joules) per year in 2010, representing 9% of the world's primary energy consumption, and 65% of the world's renewable primary energy consumption.

However, in the developed countries where forest residues are extracted for forest biomass conversion to bioenergy, the forest residues are collected in large quantity, but specified amount of these waste are left behind to improve soil fertility and other technical and ecosystem functions [5].

The primary by-products of forest resources that have not been looked into as forest biomass potential especially in Nigeria, are wastes from silvicultural activities and logging operations, which are classified in detail in Table I. While, a lot of these forest residues are usually generated after logging activities (a heap of tree branches located at the University of Ibadan is shown in Fig. 1).

A study conducted in 1989 on commercial logging efficiency in Ondo State, Nigeria [10], showed that lumber recovery from logs is usually between 45% and 50%, leaving behind 50% to 55% of log residues in sawmill processing sites. While it was revealed that the recent lumber recovery efficiency of logs from some selected sawmills in Ibadan metropolis was between 50.16% to 58.94% [31]. The authors also noted that the amount of sawdust generated from logs processed into lumber was 3.32% to 10.02%, while other solid wood residues like slabs, wany edges, shavings and off-cuts was between 32.38% to 41.23%. Thus, low logging efficiency is one of the factors that might have contributed to the deforestation of forest reserves in the country [11]. Meanwhile, secondary by-products from forest biomass are waste obtained from industrial wood residues (of plywood and particleboard industries) and waste obtained from wood processing sawmills outlets, together with fuel wood obtained from felling activities. These wastes, if harnessed properly coupled with the appropriate technological application, can generate forest biomass energy that can lessen environmental impact that is attributed to energy production and consumption [25].

Table I: *Sources and Types of Wood Residue*

Source	Wood Residue
Forest operation	Branches, stumps, roots, low-grade and decayed wood, slashings, and sawdust
Sawmill and planning	Bark, sawdust, trimmings, split wood, planer shavings
Plywood production	Bark, core, sawdust, veneer clippings and waste, panel trim, sander dust

Source: [5]

A. Overview of Secondary Forest By-products in Southwest Nigeria

Table II presents forest reserve capacity in South-western Nigeria. Some secondary by-products of forest biomass are usually seen to be mammoth heaps of wastes usually close to the sawmill sites. These wastes are usually burnt in the open air causing serious air pollution forming particulate matter and serious environmental waste management problems. For instance, Lagos and Abeokuta generate 810 tonnes and 1,340 tonnes of wood residues per day, respectively [22,23]. Whereas, other States in the South-western region generate smaller tonnes (Fig. 2).

Table II: *Forest reserves and plantation in Western Nigeria*

State	Area of Forest Reserve (ha)	Area of Forest Plantation (ha)
Lagos	12,579	2000
Ogun	273,118	35,000
Oyo	336,563	8,031
Osun	86,057	6381
Ondo	337,336	27,153

Source: [13]

The secondary by-products generated from sawmills in Nigeria include sawdust, off-cuts, chips, bark, shavings, and flitches among other wood wastes. In terms of volume of sawdust generated annually, Nigeria is reported to generate between 1.8 and 8.6 million tonnes of sawdust per annum [22, 18] which can be a potential source of bioenergy and biofuel production in the country. A typical picture of sawdust heaps in Nigerian cities can be seen in Fig. 2, while Table I presents the sources and classification of wood wastes.

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Fig. 1: *Heap of tree branches*

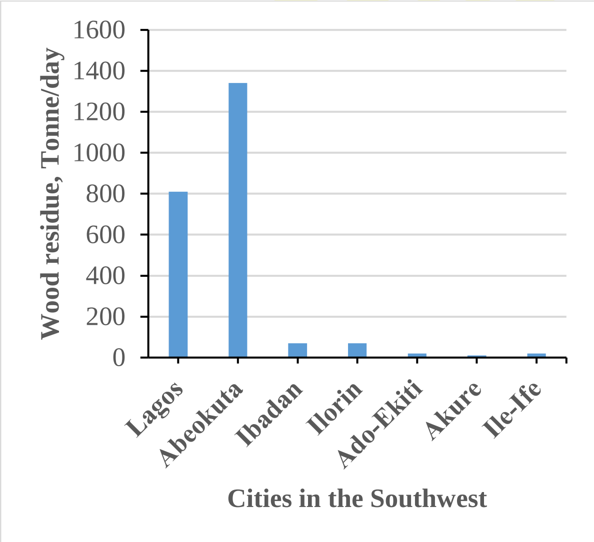

Fig. 2: *Estimate of wood residue generated in Western Nigeria, Source: [22-23]*

Fig. 3: *Heap of sawdust behind a Sawmill at Sango, Ibadan*

C. Potential of Forest Biomass Conversion Technology in Nigeria

Currently, the energy potential of forest residue is estimated to be 50,000 TJ [36] and there are several technologies that can be applied to convert such wood waste into electricity and other useful energy bio-products. The common woody/wood residue biomass conversion technologies that generate heat and power production are gasification and combustion systems which consist of co-fired and direct-fired systems [25], although some of these biomass conversion technologies are considered to be capital intensive (especially from a large to medium scale power capacity) to be applied in Nigeria rural communities. However, one of the biomass technology power systems that can be developed without enormous capital investment is the mini-grid system. According to a recent review, a mini-power plants of three-phase AC low-tension can distribute power supply to communities and business outlets for about 8 to 10 hours daily, depending on the capacity of the mini-power plants [22].

On the other hand, modular electricity generating units which comprise micro turbines using forest biomass as a feedstock to generate electricity ranging from 1 kW to 50 MW, can be applied in the Nigeria context. It was reported that Revonergy Plc, UK and the government of Ondo State initiated an agreement to build 14 MW small-scale power plant using wood waste and sawdust as feedstock to the power plant in Nigeria. Also, in another similar development, report of functional power-power plants using sawdust as feedstock was also recorded in Ile-Ife, Osun State [22]. With reference to the evaluation of biomass conversion technology engines for power supply generation, it is noted that internal combustion engine has better electric output performance than other power plants like gas turbine, micro-gas turbine, stirling, and steam power plants [6](Fig.4).

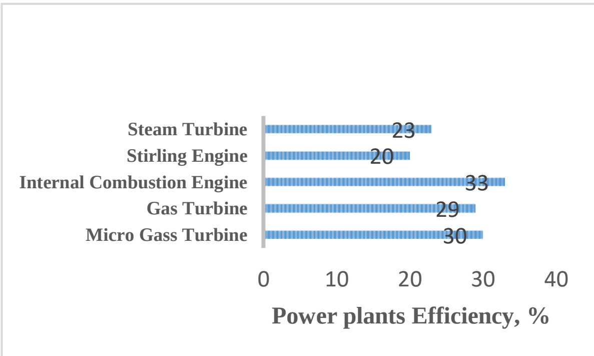

Fig. 4: *Types and power plants efficiency, Source: [22]*

D. Agricultural Biomass

Nigeria has 69,123,450 ha of arable land which produces subsistence crops like maize, cassava,

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sorghum, yam, beans, rice, groundnut and to a lesser extent are millet, soybean and cocoyam. While, the main cash crops of the country are palm oil, cotton seed, cocoa, cashew and sugarcane. And a lot of these crops generate vast amount of waste after they are being processed for consumption.

Nigeria, an agrarian country, with a capacity to produce agricultural waste for sustainable power generation, uses both traditional and mechanized methods for its agricultural activities which is dependent on the economy of the farmer. The agricultural residue generated are mostly located based on the natural vegetation regions and are generated from post-harvest activities, which is considered to be by-products of mill industries processing crops for consumption. Large scale agro-residue are usually seen to be discarded at various points of production, which are then burnt onsite. In a household level, crop processing results in generating agricultural waste, with small amount of this waste used as local combustion stoves while the remaining larger proportion are often disposed-off to the landfills [17]. The huge agricultural residues-biomass potential of the country of Nigeria is about 1.09 EJ [36], which could be one of the most reliable bio-energy resources.

E) Argument on Energy Crops for Renewable Energy Production in Nigeria

Energy crops, as it is utilised in developed countries, are cultivated so as to serve as feedstock in energy industries. Some of the current trend in the application of energy crop as a renewable energy, is the use of fast growing plants that have qualities such as, good energy density, fast growth and low cost of cultivation and maintenance [35]. The edible agricultural crops that are considered for energy production are sorghum, sugarcane, cassava, maize, oil palm, soybean. While, the inedible crops are jatropha, and various form of grass such as miscanthus, short rotation coppice (SRC), switchgrass, alfalfa and canary grass among others [34, 35]. For instance, miscanthus otherwise known as elephant grass (Fig.5) has been well-known to produce biofuel to replace coal in power stations in Europe [41].

Currently, because of the need to reduce food insecurity due to the growing population, the government still imports wheat, rice, diary from neighbouring and other international countries, despite their current positive developments and initiatives in engendering agricultural activities in the country [9]. A factor that may aggravate and contribute to the food insecurity in the country is the effect of climate change (causing either insufficient rainfall or over flooding). For example, the States where extreme flooding were recorded in the fall of 2020 were Jigawa, Kano, Kebbi and Sokoto States [32]. It was reported that about 90% of crops (majorly rice farms) were destroyed in Kebbi State alone [33]. Hence, giving the high poverty index, the growing population, effect of climate change on agricultural activities and farmer-herder clashes alongside other allied insecurity challenges in Nigeria, it is wise to say that the country should leave out edible crops for bioenergy production while the inedible agricultural crops like jatropha and different forms of grasses should be adopted into the renewable energy scheme. It is logically, therefore, to reasoned that if energy crops are added to the bioenergy scheme of the government, it will further increase the strain on food insecurity consequently incurring inflation on food prices in the market, thereby making it very difficult for the common man to afford a meal.

In countries where energy crops (especially edible ones) are converted into bioenergy products (in large scale) using conversion technologies, they incorporate modern and mechanise farming technologies in their agricultural activities which results in reaping bountiful harvest. With such bountiful harvest, it can be considered to be sufficient and in excess for their population. In Nigeria most of the agricultural activities still rely on traditional methods of farming [42], hence the utilisation of agricultural crop residues for the production of bioenergy/biofuel products using current biomass technologies. Maybe, in the future when the country has successfully lifted more than 100 million people out of poverty and addressed the challenges related to food insecurity then the country can go ahead with the edible energy crops in renewable energy applications.

F. Application of Agricultural Biomass Conversion Technology in Nigeria

One of the agricultural biomass technologies that have been domesticated in Nigeria, is the gasifier power plant located at Ekwashi Ngbo in Ohaukwu local government area, Ebonyi State. It is reported that this power plant, through the effort of the state government and United Nations agency, generates about 5.5 MW using rice husk and other available waste materials [24]. Meanwhile, another gasification plant in other parts of Ebonyi State generates 25 MW electricity capacity using rice husk as feedstock. It is said that this gasification plant of 25 MW capacity powers street lights, provide electricity to primary health care centre, information and communication (ICT) centre and an existing palm kernel processing plant. Also, in another development in the same State, there have been a report of another established gasification plant, which is aimed at supplying electricity to small-scale rice millers, Ebonyi agro-rice mills, local traders and Oferekpe mega water

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scheme [38, 40]. Hence, many of these biomass conversion technologies are needed across the country, especially in rural communities, so as to meet the projected electricity capacity demand of 98,000 MW as reported in [24].

Fig. 5: *A potential Elephant grassland at Tafawa Balewa Hall, University of Ibadan*

F. Evaluating the Performance of Forest versus Agricultural Biomass in Gasification Technology

Gasification has been considered to be one of the most efficient green conversion technology that can convert various biomass feedstock into different bio-products for various applications. Gasification is simply the thermo-chemical conversion of biomass materials into gaseous state (Fig. 6).

This technology has been noted to be a versatile and flexible in feedstock thermal decomposition between medium to high temperature condition while at the same time reacts with gasifying agent that include either oxygen, air, steam, or carbon dioxide to produce syngas of high calorific content i.e. consist of gases such as H¬¬¬¬¬¬¬¬¬¬2, CO CO2, CH4, C2H6, and other traces of higher hydrocarbons [26, 3]. The current stages in adopting gasification in developing countries are either evaluating the feasibility of biomass gasification technology or they are at the stage of introducing the technology in small-scale biomass gasifiers [2].

Therefore, in comparing the feedstock performance of forest residue vis-a-vis agricultural crop biomass; forest residue of lower moisture content between 18% and 25% have been noted to perform better than agricultural crops in biomass gasification systems [22].

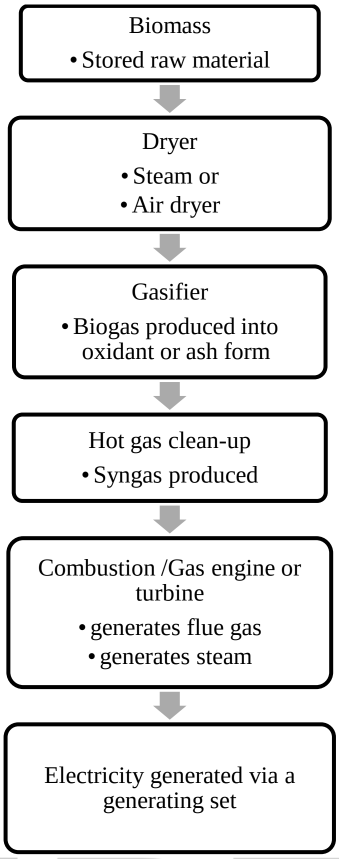

Fig. 6: *Converting Forest Biomass into electricity generation through gasification technology*

G. Gasification Development in Nigeria

Gasification technology power plants have not been developed in large scale in Nigeria, but research and developmental activities have been carried out through the University Research Program in some universities [36] and this gasification pilot plants have been reported to be present in some universities situated at Sokoto, Ile-ife, Maiduguri and Nsukka. It was further reported that there is a propose plan by the government to develop and build large gasification plants in Niger and Ogun States [37].

H. The Current Situation of Nigeria's Power Sector

Nigeria's electricity generation capacity stood at 12,664 megawatts (MW) in 2017, out of which 10,522 MW (83%) was generated from fossil fuels; 2,110 MW (17%) was from hydroelectricity; and 32 MW (1%) was from solar, wind, biomass and waste [28]. However, the net electricity generation output for a population of about 200 million people at that time could only have access to 3,495 MW in 2017 (which was 28% of the total capacity). However, a recent report stated that the total electricity generation capacity in Nigeria is 12,522 MW [24], which is 87% less than the expected electricity generation capacity of 98,000 MW for 206.1 million populations [30]. Currently the net electricity generation

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stands at 3,800 MW out of the total 12,522 MW capacity. This singular shortfall in electricity generation, transmission and distribution is one of the factors that have denied 45% of the populace access to electricity [24].

In the recent 12,522 MW electricity generation capacity, renewable energy resources of hydropower accounts for about 19%, while biomass sources contribute 1%, as stated in U.S. Energy Information Administration report. Based on the contribution to the national grid, majority of the sources that produce electricity generation come from non-renewable energy (which consist of natural gas and coal) while the remaining 19% are from renewable source of hydropower generation which is connected from 200 dams across the country generating 2000MW [38, 39, 40]. The current challenges experienced in Nigeria's power sector are poor maintenance of electricity generation facilities, shortages of natural gas supply, and inadequate transmission and distribution network [14]. The current potential of renewable resources in Nigeria (if harnessed properly) is estimated to be over 68,000 MW [24], which is seventeen times the current net electricity generation.

Nigeria is still grappling to increase renewable electricity generation to more than 20,000 MW and to increase hydroelectricity generation to 5,690 MW by 2020, unfortunately the country has been unable to achieve this goal in 2021. Some of the hydropower projects that have been approved by the government in time past to achieve the 2020 target include: Gurara II (360 MW), Zungeru (700MW), Mambilla (3,050 MW) and Kashimbila (40 MW), and rehabilitation of Jebba (578 MW) and Kainji hydropower projects (548 MW). Some of the power projects, according to reports, were due for completion between two to three years, unfortunately the delay in executing this power projects have been fraught with legal challenges [28-29].

In solar power projects, there has been growing interest from the Nigerian government and investors in the past few years, to create alternative resource to natural gas supply and increase electricity access to remote and rural areas. Unfortunately, the growing interest of the government have not materialised into completion of projects due to the in-ability of Nigerian government and the international organisation to reach financial obligation. One of the proposed solar project of the government were: the rural electrification project from a joint funding from World Bank and the Nigerian government which cost a tune of $75 million grant to encourage off-grid solar investments. Thus, the aim of the project was to reduce kerosene and diesel use for electricity supply and backup power generation. In 2016, Nigeria signed power purchase agreements with 14 utility scale solar photovoltaic facilities that had a total generation capacity of 1.1 GW [4, 1, and 28].

On renewable energy, recent reports have it that Nigeria and the European Union reached an agreement for renewable energy master plan, to launch an electrification master plan in 2011 seeking to increase the renewable energy generation to 23% by 2025 and 36% by 2030 [29]. In order to achieve this target, both parties proposed installation of 500 MW solar photovoltaic, 400 MW biomass power plants, and 40 MW wind power plants by 2025; so that 75% of the populace can have access to electricity.

IV. CONCLUSION

This review x-rayed the current condition of the power sector and the initiatives government have taken to ensure electricity access to larger population (especially to rural communities that are remote to the national grid), thereby fulfilling the Sustainable Development goals and target of the United Nations. Also, this review classified forest biomass resources into primary and secondary by-products.

Primary by-products are wastes generated primarily from the forest during silvicultural activities and logging operations, while secondary by-products are wastes generated from sawmill outlets and wood product industries. Waste conversion power plants that use forest and agricultural crop residues as feedstock were reviewed and was found that combustion system power plants were more efficient in terms of electricity output than other forms of power plant systems.

Records of biomass-power plants built in the country were reported, unfortunately, many of these power-plants have not been confirmed to be functional presently. Therefore, there is the need for further research, in the area of identifying functional forest/woody-based and agricultural residues power plants across the country.

So that, such functional plants may be a source of model for public and private universities as well as institutions that will like to replicate such model using local content in the fabrication of these power plants in a pilot scale.

Thus, by so doing, it will engender research in the country and gradually provide manufacturing solutions of bio-based power plants with less cost than what is obtainable in Europe and America, and more importantly solve the energy crisis currently experienced in the country.

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