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Research paper

A review on waste to biogas sources and its potential in Nigeria

Okoro Emeka Emmanuel [1] *, Igwilo Kevin C. [2], Sanni E. Samuel [3], Orodu Kale [1]

[1] Petroleum Engineering, Covenant University Ota, Nigeria
[2] Petroleum Engineering, Federal University of Technology Owerri, Nigeria
[3] Chemical Engineering, Covenant University Ota, Nigeria
**Corresponding author E-mail: emeka.okoro@covenantuniversity.edu.ng*

Abstract

Waste to biogas initiative is one major solution to the exponential increase of solid wastes in both rural and urban cities in Nigeria. This study examines the potential of producing organic waste materials for biogas and its benefits to the immediate councils where these organic waste are found in abundance. The choice of organic materials was based on reports from characterization from published literature. Based on this review, it was observed that researchers have been proposing a lot of unique approaches to manage solid waste generation. Most of their emphasis is towards perfect waste collection and disposal, but these approaches are very expensive considering the tight budget that the country is faced with. Various studies on this subject have been compiled from 2001 to 2017 and their outcomes and discoveries have been highlighted to show the importance of converting these organic wastes to biogas. The production and use of renewable energy sources are justified not only by energy, environmental and competitive aspects, but also on the aspect of rural development. These wastes have been identified in this study as huge sources of biogas which can be used to solve some of these council's energy problems in their locality. This review also shows that new technologies are available to harness these opportunities; and the economic analyses done in some of the reviewed articles showed good payout periods when a large bio-digesters are used. This study showed that organic wastes are in abundance and at a very low cost, and the study further identified that some rural communities experience huge post-harvest organic wastes from their farms, thus, a good spot to start the implementation process for this initiative.

Keywords: *Biogas; Organic Waste; Solid Waste; Sustainable and Renewable Energy; Waste to Biogas; Post-Harvest Waste.*

1. Introduction

In accordance with the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal of 1989, Article 2 (1), "Wastes are substances that are to be disposed off, or are envisioned to be essentially disposed [1]. The Glossary of the United Nations Statistics Division on Environment Statistics [2] describes waste as "non-essential materials" (that is, products intended for the market) of which the generator considers no longer useful for its own purposes of production, processing or consumption, hence, she/he wants to get rid. Wastes can be generated when extracting raw materials, processing raw materials into intermediate and final products, consuming end-products or from other human activities. In accordance with the Waste Directive 2008/98 / EC, Article 3 (1), the European Union defines waste as "an object that the owner discards, intends to dispose off or discard" [3].

There are several types of waste identified by modern waste management systems, as shown in table 1; they include municipal waste (domestic waste), commercial waste and waste from demolition; Hazardous waste (industrial waste); Biomedical / clinical waste (clinical waste); Agricultural waste; hazardous wastes (radioactive waste), explosive waste and electronic waste; end-of-life automobiles; construction and demolition waste [3]. According to [4], wastes differ in form, origin, size, physical and chemical composition. Thus, they are classified as liquid, solid and gaseous. For the purpose of this study, we will limit our review on solid wastes in Nigeria.

In Nigeria, waste management has become a serious problem, despite several attempts by successive governments and private organizations in this direction. Across the country and market areas, it is common to meet or see piles of festering waste dumps in almost every corner. Residential apartments, markets, waterways, roads and undeveloped lands have been converted into waste dumps for many families. Not surprising, many say that waste in Nigeria is increasing exponentially, and collection and disposal are in arithmetic progression. According to [6], Nigeria with population that exceeds 160 million people generates close to 32 million tons of solid wastes yearly, but only 20-70% of the said amount are properly collected.

Table 1: Sources and Types of Solid Waste [5]

Source	Typical Waste Generators	Types of Solid Waste
Residential	Single and multi-family dwellings	Wastes from food items, paper, rubber, plastics, wood, textiles, leather, glass, metals, ashes, special wastes
Industrial	Heavy / light manufacturing, construction sites, fabrication, Energy and chemical plants.	Housekeeping wastes, food wastes, wastes from demolition sites, construction materials, hazardous wastes, packaging, and ashes.
Commercial	Stores, hotels or restaurants, markets, office buildings.	Paper, wood, plastics, metals, food wastes, glass, special wastes, hazardous wastes.

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Institutional	Government centers, Schools, prisons, renovation sites, and hospitals.	Mostly the same as commercial.
Construction and demolition	New construction sites, demolition of buildings and road repair.	Wood, rods, metals or steel, concrete, blocks etc.
Municipal services	Beaches, other recreational areas, landscaping, parks, Street cleaning and plants for wastewater treatment.	Street sweepings; sludge, general wastes from parks, beaches, landscape and tree trimmings; and other recreational areas.
Process (manufacturing, etc.)	Refineries, Heavy and light manufacturing, Processing and mineral extraction plants, Energy and chemical plants.	Industrial process wastes, off-specification products, scrap materials, tailings and slay.
Agriculture	Crops, Farms, orchards, dairies, vineyards, and feedlots.	Spoiled food wastes, Post-harvest waste, agricultural and hazardous wastes (e.g., pesticides).

The study [7] classified Nigeria as a developing country after considering the availability of economic resources and the availability of technological resources and the range of mechanization applied in process industries. Their basis for classification was that the rate of generation of waste by a region or nation is a function of the economic activities within it. They also noted that solid wastes from developed and developing nations vary widely. According to [8], characterization of solid wastes from a region helps determine the amount of wastes generated at a given location and at a certain time of the year. This helps to determine the generation trend, as well as the influence factors.

2. Composition and characterization of waste in Nigeria

Wastes from rural areas consist mainly of biodegradable materials, and those that are generated in urban areas or in cities are partially biodegradable, toxic, flammable or hazardous. In Nigeria, research has shown that 80% of the total waste generated is predominantly organic [9; 10]. The compositions of solid wastes in the municipal areas vary depending on the place in which it is collected, and the season.

The enormous problems associated with the creation, collection, disposal and management of wastes in urban areas of developing countries have been widely documented [11 - 20]. In an attempt to meet the needs of nature conservation and natural resources, it is very important to know the composition of the waste in order to dispose them and manage them properly. One of the problems faced by Nigerian urban centers is the issue of waste management [11]. The cities of Nigeria, being one of the fastest growing cities in the world [20], face the problem of production and management of solid wastes. The consequences are serious when the country is growing rapidly, and the waste is not effectively managed. Inadequate disposal of solid domestic waste presents a potential danger to the environment and the natural ecosystem of the host country.

Available literature shows that the physical characteristics of urban solid wastes are based on the density of residues, their physical compositions, their moisture contents, chemical composition, and the particle size distribution. Characterization of the residues is also carried out on the basis of flammability, organic composition and microbiological population, respectively [21]. From most literatures reviewed, characterization of waste begins with collecting waste from the source and separating it directly into material types. The weighing of the source and the sorting of household wastes at the source facilitates and the identification of waste eliminates any uncertainty regarding its source [22]; [23]. Literature from Nigerian authors have shown different classifications of wastes in their studies and table 2 shows some of the categories identified by different authors.

From various researches and studies in Nigeria, most of the classifications are unique and same. But the individual categories or components of wastes used for different analyses differ (table 2). Ease of analyses seems to be the simple reason we can deduce these findings from reviewed literature reviewed. Though, the basic components such as Paper, Plastic, Food waste, Metal, Nylon are common for all studies under review.

Table 2: Classification and Categories of Waste by Different Authors

Authors	Categories/ Components	Classification
Igwe et al., 2002	Trash, Metals, Glass, Polyethylene and Plastics, and Biodegradable	Biological, Chemical and Physical character
Oyelola and Babatunde, 2008	Paper, Putrescible, Nylon, rubber and Plastic, Metals, Glass, and Garden waste	Biological, Chemical and Physical character
Kadafa et al., 2012	Paper, Metal, Glass, Plastic, Food remnants, Textile, Rubber, Others and Person/ household	Biological, Chemical and Physical character
Babatunde et al., 2013	Organic, Paper, Plastics, Metals, Glass, Nylon and Others	Biological, Chemical and Physical character
Okey et al., 2013	Plastic, Paper, Metal, Glass, Textiles and Others	Biodegradable materials, Slowly biodegradable and Non-biodegradable waste
Ogu et al., 2014	Paper, Plastic materials, Glass/ Bottle, Nylon/ Polythene, Metals/ Cans, Textile materials, Food waste, Ashes, Animal dung, Garden waste/ Leaf and Special waste	Biological, Chemical and Physical character
Abur et al., 2014	Food, Paper, Iron, Glass, Rubber, Plastic and Others	Biological, Chemical and Physical character
Butu and Mshelia, 2014	Tins, Plastics, Bottles, Food waste, Ash, Dirt and Vegetables	Biodegradable and Non-biodegradable wastes
Audu et al., 2015	Paper, Metal, Glass, Organics, Plastics, Nylon, and Others	Biological, Chemical and Physical character
Bovwe et al., 2016	Organic, Plastics, Paper, Glass, Metal, Textile/ Leather and Unclassified Debris	Biological, Chemical and Physical character

Solid wastes are considered to be wastes generated as a result of operational activities carried out in various areas of land; such as residential, commercial and industrial. Household or Domestic waste is one that is regularly collected from households, such wastes include organic substances that are formed as a result of cooking and consuming food, rags, nylon and ash. Commercial wastes are produced from stores, supermarkets, markets and others; these include cardboard, polyethylene and nylon bags. Industrial wastes are wastes obtained from industries; they can be solid, liquid or lubricants, and are said to be toxic, hazardous and special. Industrial wastes include metals, rubbish, chips and machine grains, sawdust, pieces of paper and glass [24].

According to [25], Fig. 1 can be used to relate the sources and percentage volume of solid wastes in most cities in Nigeria.

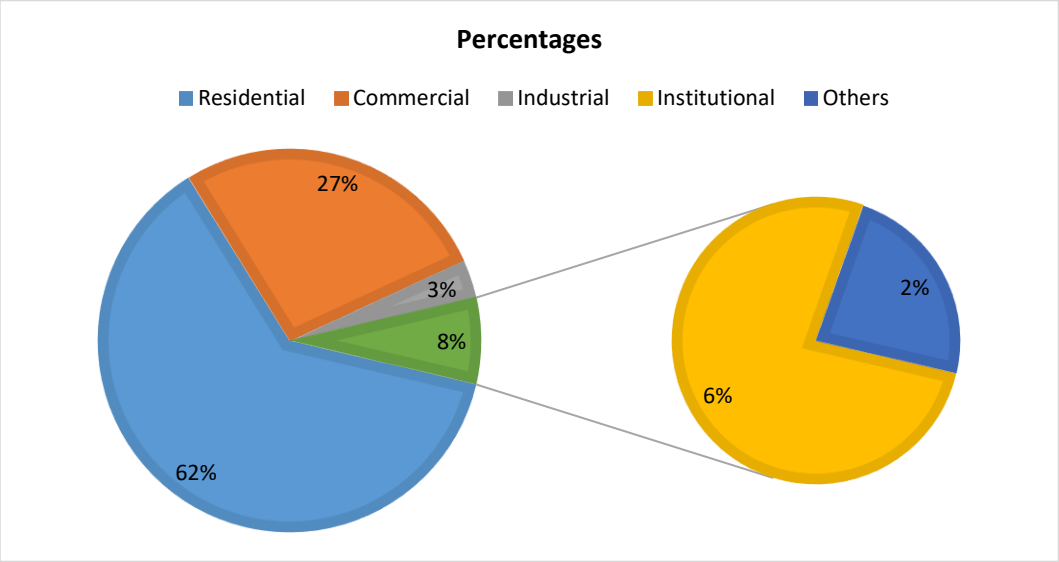


Fig. 1: Sources of Solid Waste in Most Cities in Nigeria [25].

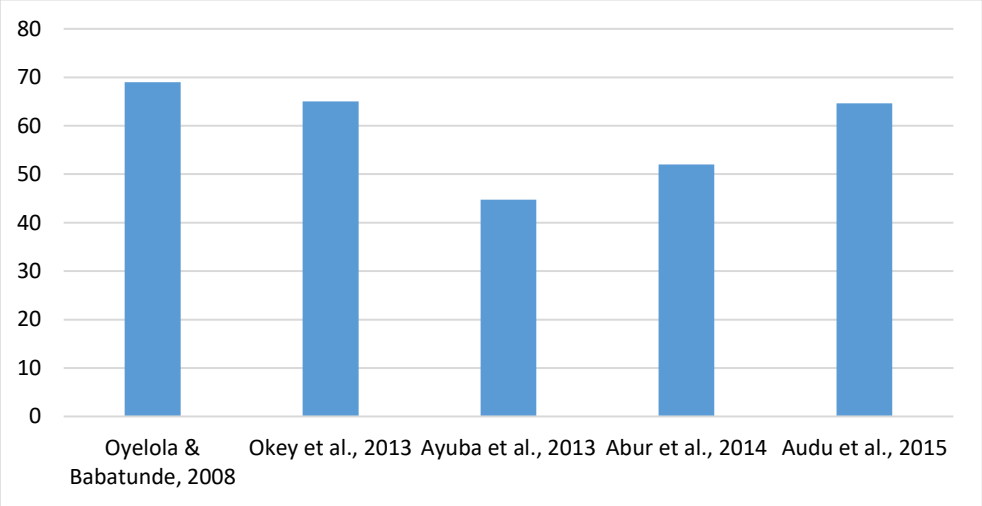


Fig. 2: Percentage Volume of Organic Content in Different Solid Waste Studies.

Figure 2 illustrates the percentage volume of organic content in solid wastes generated in most cities. This study is focused on organic materials present in these solid wastes which can yield energy or biogas.

The study by [26] on feasibility of waste to energy shows that organic biodegradable substances produce energy in such a way that they can be effectively used under the right conditions. In addition, the components of solid wastes have intrinsic or potential energy values, which can be used by several technological processes as an alternative energy source. The energy content of solid waste is the heat of combustion (upper or lower heat of combustion), which is released during the incineration of waste. A lower calorific value usually excludes heat from evaporation of water, in contrast to a higher combustion temperature. The composition of the waste stream is an important feature necessary to determine the choice of a technically and economically feasible waste processing process for this waste stream.

The energy potential of organic solid waste components can be mainly used in two ways: (i) thermochemical transformation; and (ii) biochemical conversion.

3. Waste and biogas

The use of biomass for energy production is one of those alternatives that have recently become attractive around the world as a source of clean and sustainable energy. Another problem of concern in the developing countries is the effective disposal of solid wastes [27]. According to [27], the biodegradable part of these wastes is associated with uncontrolled releases of methane. They also identified anaerobic digestion as one of the technologies for processing solid organic wastes for production of biogas and methane. These products can serve as natural gas and liquid petroleum gas alternatives. The other advantage of anaerobic process is that the residue from the solid organic waste used, produces an organic material that can be used as bio-fertilizers directly on farm lands, thereby, replacing artificial fertilizers. This anaerobic process offers energy production with huge environmental benefits.

Any biodegradable material of animal or plant origin can be used to produce renewable energy (methane or biogas) during anaerobic digestion. Plant materials, (weeds, plant remains, aquatic plants, etc.) are also major sources of methane production. Gas production is best if these materials are mixed with human waste or animal waste. Various agricultural residues, such as wheat straw, rice straw, vegetables, and so on, have been used in combination with animal wastes to produce methane. For the development of biogas, it is necessary to know the waste-to-gas-potential in a country. Biogas is a combustible gas obtained by anaerobic fermentation of organic materials through the action of methanogenic bacteria. Among other factors, methane production also depends on the ambient temperature.

Studies on the effect of waste paper on biogas production from plant and animal waste was carried out in Nigeria [28]. They established the specific combination of these solid waste materials that will yield maximum biogas. They also developed a first order kinetic model for this process and concluded that the waste paper in the process optimized the yield of biogas; and it was deduced that this

process can help in the disposal of waste paper generated in-country [29]. The study of Meggyes and Nagy [30] proposed a suitable method for providing continuous operation in producing and utilizing biogas; and also identified parameters needed to sustain and fully utilize a biogas plant.

Most agricultural and culinary wastes are organic materials with great calorific and nutritional values for microbes, so the efficiency of methane production can be improved by several orders of magnitude, as indicated above. This means that the efficiency and size of the reactor, and the cost of producing biogas is reduced. In addition, in most cities and places, kitchen and agro wastes are disposed off in landfills, which creates a risk to public health and diseases such as malaria, cholera and typhoid fever. This is a typical case in some cities in Nigeria; inadequate waste management, such as uncontrolled discharge, is associated with several negative consequences: it not only leads to contamination of surface and groundwater through the filtrate, but also contributes to the creation of flies, mosquitoes, rats and other carriers of diseases. In addition, it releases unpleasant smells and methane, which is an important greenhouse gas that contributes to global warming [31].

The use of agro and animal waste was exploited for biogas production and they concluded that the environment and temperature of digester affect the anaerobic yield of the process [32]. They proposed that the use of biogas as an alternative source of energy should be intensified because of the benefits. Most cities in Nigeria are faced with solid waste management problem, most of these wastes are perfect feeds for these anaerobic process. Furthermore, stakeholders and other private companies can invest in this alternative source of energy to solve both environmental and health related issues associated with these cities.

The average composition of bio-methane is shown in Table 3 while the general features of biogas are presented in the study by [31]. According to [33], methane produced during anaerobic digestion of waste can be used for cooking. Also, the methane can be used for home heating and power generation after some conditioning process.

Table 3: Biogas Composition [30]; [31]

Substance	Symbol	Concentration (Volume)
Methane	CH_4	55 – 65%
Carbon dioxide	CO_2	30 – 40%
Hydrogen	H_2	0 – 1%
Nitrogen	N_2	0 – 2%
Nitrogen Oxide	N_2O	0.3%
Water Vapour	H_2O	2 – 7%
Hydrogen Sulphide	H_2S	20 – 20,000ppm (2%)
Ammonia	NH_3	0 0.05%
Oxygen	O_2	0 – 2%

4. Nigeria present situation

Federal and State governments in Nigeria have invested largely in agriculture in order for the country to be self-dependent. The irony of it all is that, most of the farm products end up as wastes because of many reasons such as inadequate storage facilities, lack of steady power supply, and high cost of transportation; and so on. According to the study by [34], most local governments in Nigeria still have high post-harvest waste generations and they often have problems in discarding them from their farm areas.

To be effective, solid waste management program needs financing. Unfortunately, especially in a dry budget era, it is very difficult to find the necessary resources. In fact, waste collection and disposal in most Nigerian cities has become complex, expensive and capital intensive, such that it is a futile effort to expect that one council of local government or the state ministry will finance them with limited resources. The question is, how can the body that plays a decisive role in ensuring the efficiency and effectiveness of the environment function effectively when it is heavily underfunded?

One of the solutions offered from this study is the advocacy and implementation of intensive waste to biogas initiative. These wastes have been identified in this study as huge sources of biogas which can be used to solve some of these council-energy problems in those localities.

A study shows the energy potentials of some agro waste commonly found in Nigerian solid waste [35]. The researchers noted that these materials have good heating values than some biomass-fuel materials. They also noted that the heating values are within the range of the production of steam in electricity generation, thus, they encouraged possible substitution of energy materials for industries using biomass for energy in Nigeria. The heat contents of these common solid waste materials are presented in figure 3 while figure 4 presents their ash content in percentage.

In another study [36], the authors highlighted that Nigerian agriculture creates a huge amount of wastes that can be converted into renewable energy sources to increase the country's primary energy needs. They also noted that renewable energy potential in Nigeria agro and animal wastes is huge and can be used to provide alternative fuels such as ethanol, biogas and solid fuels, both for use in power generation. Their study recommended that these renewable sources of energy be used for agricultural- and rural community power generation. It also highlights the potential for animal dungs to produce energy in Nigeria, as the Nigerian livestock increases yearly.

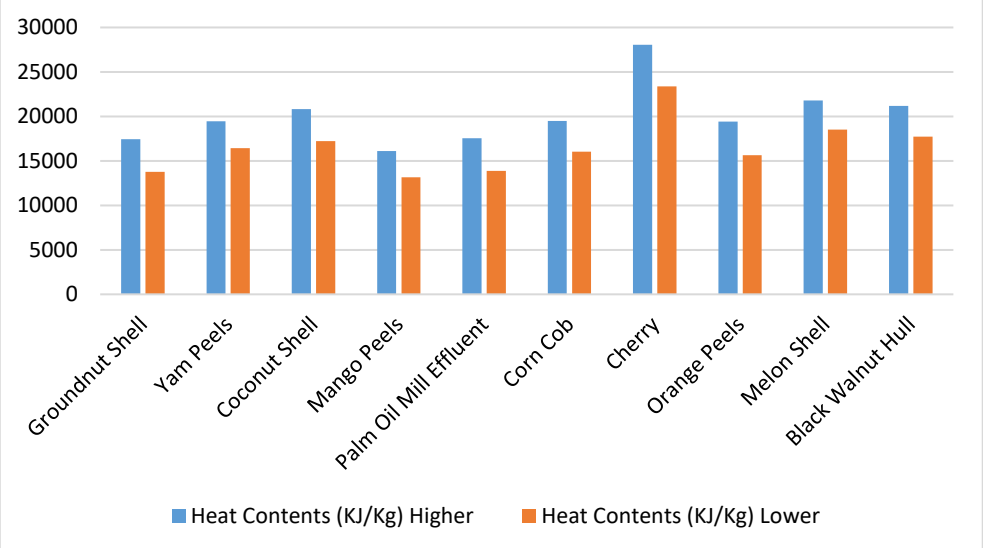


Fig. 3: Heat Contents of the Selected Waste [35].

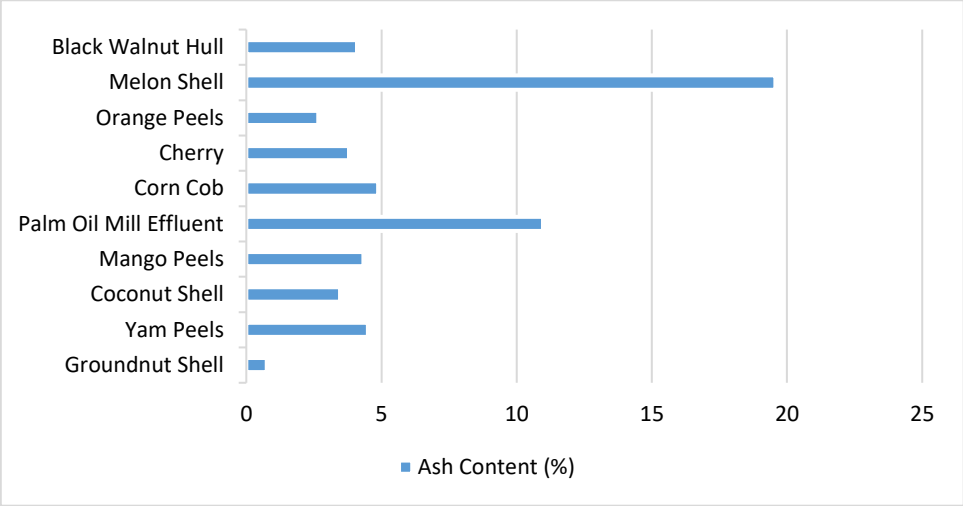


Fig. 3: Ash Contents of the Selected Waste [35].

Wastes generated from the agricultural sector in Nigeria though huge and considered worthless, can serve as raw materials for biogas which is capable of sustaining and supporting wealth creation in-country. There is need for the government and all stakeholders within and outside Nigeria to bridge the technological gap in intensive commercialization of research products on waste to biogas particularly in universities, because there is a viable technological nucleus to propagate the use of 70 -92 percent of solid wastes generated in Nigeria.

5. Waste to biogas potentials in Nigeria

The current needs of sustainable urban development are aimed at focusing on environmental issues in an overall decision-making process. In urban areas, major environmental problems are usually associated with air quality problems caused by transport activities. Another important problem is the increase in the amount of wastes and inefficient handling of wastes which are common in most cities. According to [37], most African countries have the challenge of converting waste to biogas. They also noted that the technology of biogas production will become a collective solution to both of the above problems cited above. Given the numerous technological advantages and Nigeria's population, it is expected that biogas technology will be widely spread in the country. However, progress in biogas technology is hampered by the lack of government commitments, lack of adequate processing skills, ineffective waste management, insufficient knowledge of technology and its associated benefits [37]. Barriers were identified, and the need to intensify efforts to overcome them. The potential of biogas technology in Nigeria is excellent. Literature have shown that for anaerobic digestion of 542.5 million tons of organic waste produced annually in Nigeria, can generate 25.53 billion m^3 of biogas or produce 169,541.66 MW of energy which address some of the immediate council energy problems. In addition, as a by-product of the digestive process, it is possible to annually produce 88.19 million tons of bio-fertilizers which will reduce the use of synthesized fertilizers. This will have a significant impact on agriculture, the level of deforestation and public health, and will improve the country's economy cumulatively/in the long-run [37].

According to [38], the use of biogas from agro biogas plants is a progressively significant element for power generation distribution. In [39], they identified the potential of producing biogas from animal waste. There is a growing trend towards an increase in the number of cattle in response to the growing demand for animal products that lead to the production of more organic wastes on farms and various slaughterhouses. They noted that the treatment of animal wastes through anaerobic digestion or biogas technology can potentially contribute to the formation of a huge number of renewable energy sources [39]. Biogas has a new open window for replacing natural gas. Many scientists have proposed the use of high-tech technology for waste processing. Some studies have also attempted to discuss various technologies for biogas treatment that are widely used around the world and key technologies in development or research. Widely adopted technologies are significantly important as a result of their modes of operation [40].

The study [41] discussed new technologies in China that are used to develop biogas from waste. With these new technologies and cheap source of organic wastes all over Nigeria, we can say that the potential of biogas as a solution to basic challenges of energy, agriculture and waste management is more real than ever. According to [42], the initial investment cost for biogas plants is reduced when the size of the digester is large and this will reduce the number of biodigesters needed for a particular area or council. Economic analyses show that the dimensions of these digesters will be viable with a positive net present value (NPV) at a nominal rate of 18% to 37%. The payback period varies from 1.3 to 3 years, depending on the size and amount invested [42]. A study also reports on the economic viability of this process [43]; they noted that this process can become reliable energy source and clean energy alternative which also provides bio-fertilizer for agriculture.

6. Summary

Nigeria is currently facing air and solid waste pollutions as a result of poor solid waste management and high dependency on fossil fuel as a source of energy. Other challenges are urban migration and post-harvest generation of agro wastes. Though, the process of waste to biogas has been treated by some researchers' in-country, a good number of Nigerians have little knowledge of what the process has to offer. The lack of experience on the technology of anaerobic digestion and biogas production from waste; and non-valuation of biogas production program to meet local needs is actually having its toll on the country in general. Given the numerous technological advantages and the ever-increasing Nigerian population, it is expected that biogas technology will be widespread in the country. However, progress in biogas technology is hampered by lack of government-commitment at all levels. Wastes generated from the agricultural sectors in Nigeria though huge, and considered worthless, can serve as raw materials for biogas which is capable of sustaining and supporting wealth creation in-country. Thus, there is need for the government and all stakeholders within and outside Nigeria to bridge the technological gap in intensive commercialization of research products on waste to biogas. Research has shown the potentials of emerging new technologies especially with, large digesters which can help reduce the number of plants needed in a particular area and in turn reduce the initial cost of investment. This study therefore highlights the process of waste to biogas, its benefits and the potentials that exist in Nigeria for its development. It is also expected to serve as a guide for in-country utilization of organic solid wastes in order to contain the challenges of energy and clean

environment which have a direct impact on the Nigerian economy and its citizens.

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