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Biogas Production from Municipal Solid Waste: An Energy Imperative for Nigeria

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ABSTRACT

In this study, the potential of utilizing biogas from Municipal Solid Waste (MSW), as a potent alternative source of energy in Nigeria, was vividly established. The current energy situation and extent of integration of MSW in the energy mix in Nigeria was critically examined. The energy potential of MSW in Nigeria was determined, especially in relation to the quantum of MSW generated in the country. This was done in juxtaposition with energy generated from other sources in the country, with their attendant environmental implications. The trend analysis indicated a general and steady decline in the energy generation and consumption pattern in the country, in the last decade, which was attributable to her mono dependence on fossil fuel.

KEYWORDS: alternative energy, biogas, energy mix, municipal solid waste, energy potential.

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1. INTRODUCTION

Nigeria is faced with severe energy crises, despite the abundance of a variety of natural resources. The energy situation in the country continually worsens rather than improve, even with a seeming deliberate and consistent effort by the government to address the problem. The persistence of the problem despite several years of trying would seem to imply that the government of Nigeria and her people have run short of every available idea that can ameliorate the dampening and frustrating situation.

There seems to be several reasons for this energy crisis. Principal amongst them is the glaring over-dependence on petroleum products. In Nigeria today, every life activity depends on the use of petroleum products, excepting in the electricity sector where hydropower constitutes 14.5% of the supply (CBN, 2018), and the punctuated introduction of solar power in some parts of the country. This puts pressure on the already over stretched supply of petroleum products. When the high demand pressure of an ever-increasing population is juxtaposed with the nature of fossil fuels, which are characteristically depleting and non-renewable, the necessity of alternative energy sources becomes obvious. More pertinent in this regard is the reliance of the Nigerian economy on petroleum products for foreign exchange. Presently a greater percentage of the nations of the world are shifting emphasis from petroleum products to other alternative energy sources which are renewable and environmentally friendly. The implication of this is a decline in the economic fortunes of Nigeria, which is solely dependent on the patronage of these other countries.

Even if Nigeria were able to harness her crude oil effectively, the hazardous consequences of the operation on health and the environment will also question its sustainability for continued production and utilization as an energy source in the country. The entire processes of exploration, exploitation, production, and utilization of crude oil is fraught with severe adverse environmental consequences. Pollution of water, soil, and atmosphere by way of emission of pollutants such as NOx, SO_4, CO, CO_2, VOC and PM10; oil spillage on soil and water and the attendant effects on soil and aquatic life are some of the environmental impacts questioning the sustainability of continued over-dependence on crude oil-based energy sources. More recently, the incidence of climate change and global warming, where it has been reported that methane emissions produced during extraction and transport of crude oil is the most potent ozone layer depleting gas (UCS, 2016) further questions the sustainability of the continuous use of petroleum products as major energy sources. Even when this gas is burned in flares to produce carbon dioxide, CO_2, which has a lower ozone layer depletion impact than methane, the volume of CO_2 emissions released from the combustion of petroleum products, still poses significant risk of global warming.

Nigeria is truly in need of alternative energy sources. A truth that is influencing the energy policy thrust of the government. In 2007, the Federal Government approved a technical framework for nuclear programme in the country. The target was to install up to 4000 MWe by 2025. In 2017, Nigeria signed an agreement with a Russian firm, Rosatom, to build four nuclear power plants worth 20 billion US dollars. This was a commendable effort of government to vary the energy mix in the country and guarantee a steady energy supply. However, aside from the cost intensity of these nuclear energy sources, they have tremendous adverse impacts on the environment. Nuclear power plants, for instance, produce high-level and low-level radioactive waste, which even developed nations like the United States, with all the progress in environmentally sound management of waste, is yet to dispose of effectively safely (PSR, 2016). In addition, nuclear power plant accidents prove to be more catastrophic than any other source of energy because it affects a wider landmass, and its effect can be felt several years after it occurs. An example is the Chernobyl accident which occurred in 1986, but its impact on human health was still felt 30 years after occurrence (ICRIN, 2010).

In Nigeria's attempt to diversify her energy sources different renewable and non-renewable energy types have been considered including hydropower, nuclear, solar and biomass energy. Sources of biomass energy in the country include fuel wood, saw dust, agricultural waste, and municipal solid waste (MSW) (Sambo, 2009). Fuel wood is the most predominantly used biomass energy source in Nigeria, with demands as high as 39 million tonnes per annum (ibid). This is not surprising as the rural populace, who do not have access to the conventional sources of energy resort to fuel wood for their energy needs. In addition, there are a number of small biogas plants using agricultural residues as feedstock whereas saw dust is used for mostly heating and drying purposes. The one source of renewable energy that seems to have been relegated to the background is MSW. This paper presents a holistic analysis of the imperative of generating biogas from MSW as an alternative energy source to Nigeria's mono dependency on fossil fuel.

2. MATERIALS AND METHODS

Data for this paper was obtained from extensive review of literatures and reports from national and international sources and databases. The data obtained were represented in tabular form and comparatively analyzed using simple graphical presentations.

3. RESULTS AND DISCUSSION

3.1 Status of the Nigerian Energy Sector

Energy is essentially the capacity of a person or machine to do work. Therefore, the amount of work done in any place is literally contingent upon the amount of energy available to get the work done. Therefore, energy is essential for the sustenance of every development initiative, whether socioeconomic, political, or even projections for future growth in terms of infrastructural and industrial expansion, for the ultimate comfort of the citizenry. So, energy is a *sine qua non* for the long-expected industrialization and overall development efforts of Nigeria.

3.1.1 Legislations, Policies and Strategies on Energy in Nigeria

Nigeria's energy sector is principally characterized by the petroleum and electricity industries. The National Energy Policy (NEP;

2003) is the first policy document to incorporate these two industries as a comprehensive and integrated energy policy. Previous legislations and policies considered individual energy sources leading to their being limited in scope and duplicity in functions of the agencies set up based on them. The focus of the NEP is therefore, the "optimization of the nation's energy resources to ensure sustainable development" through emphasizing the development of the renewable energy sources and deemphasizing the non-renewables (ECN, 2003). The policy addresses issues of research and development, energy security, energy efficiency, pricing and financing, legislation, and environmental issues. Other energy policies and strategies in the country include Renewable Energy Master Plan (REMP; 2012) which seeks to "integrate renewable energy in the energy supply to building, the national grid and other distribution systems" (NESP, 2015); and National Renewable Energy and Energy Efficiency Policy (NREEEP, 2015).

3.1.2 Energy Demand in Nigeria

The energy requirement of a country depends largely on the population. As population increases more energy is expected to be demanded. Nigeria would appear to be moving in the reverse of this proposition. This has been attributed to inadequate and obsolete infrastructure, poor electricity governance, policy flip flops among others. A report by Energy Vanguard (2021) revealed that the national grid collapsed three times in 5 months in 2021 and 130 times since 2013. This energy demand-supply imbalance always results in very high cost of energy in the country.

Models for estimating energy demand are based on the principle that the gross domestic product (GDP) of an economy is related to its level of energy consumption. This is to say that the more energy is available in a country, the better its capacity to produce. Additionally, the level of energy consumption will depend on energy prices as well as the spending capacity of citizens. The Energy Commission of Nigeria (ECN) developed a model for the analysis of the energy demand (MAED) based on different GDP growth scenarios. The reference scenario was 7%; and the energy demand for high growth, 10%, and optimistic growth scenarios of 11.5% and 13% GDP were estimated. The model was used to project the energy demand up to 2030. The estimated energy demand for the scenarios considered are presented in Table 1.

Table 1: Estimated energy demand (mtce) in Nigeria using different GDP scenarios

Scenario	2000	2010	2015	2020	2025	2030
Reference (7%)	45.73	51.40	79.36	118.14	169.18	245.19
High Growth (10%)	45.73	56.18	94.18	190.73	259.19	414.52
Optimistic (11.5%)	45.73	56.18	108.57	245.97	331.32	553.26
Optimistic (13%)	45.73	72.81	148.97	312.61	429.10	715.70

Adapted from Oyedepo (2012)

3.1.3 Energy Generation and Consumption

Energy generation in Nigeria is largely from petroleum products – Premium Motor Spirit (PMS), Automotive Gas Oil (AGO), Dual Purpose Kerosene (DPK), Liquefied Petroleum Fuel Oil (LPFO) and Liquefied Petroleum Gas (LPG). Other sources, which are scarcely prominent are hydropower, coal, and natural gas. Although Nigeria is the 6th largest country producing crude oil, which is the primary natural source of these resources, it has not been able to meet the energy needs of her populace both in the past and present. Nigeria is required to refine her crude oil to be able to produce the required quantities of petroleum products for her people. Her crude oil reserves, according to the NNPC (2020), is estimated at 36.9 billion barrels (4.4 billion cubic metres). Nigeria has the fourth largest refinery capacity in Africa, with its three refineries at an installed capacity of 53,062 m^3/day. Regrettably, the collective performance of these refineries has constantly been dwindling over the years, recording as low as 2.53% in 2019 and have even been shut down since 2020 (NNPC ASB, 2020). A situation that results in persistent supply lag in the country, as almost all the supplies currently are imported.

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Figure 1 presents the energy consumption trend of Nigeria from 2010 to 2019. The energy consumption is far below the estimated demand even with the 7% reference scenario. This trend incontrovertibly points to the crises in the energy sector in Nigeria. The energy generation and consumption crises usually attain a frightening level of imbalance whenever there are controversies around subsidies for petroleum products, or petroleum products workers embark on an industrial action to back agitations for increased wage demand, or any other such issues related to petroleum products utilization. Therefore, it is easy and possible to assert that Nigeria's energy crises are directly caused by an over-dependence on fossil fuels, particularly petroleum products, as it arises in the situation heretofore highlighted, despite the continued sustenance of other running energy sources in the current energy mix. Within the period under review, energy prices increased by 100% compared to gross national income per capita, which declined from 4.6% in 2010 to -4.6% in 2019. Despite that the country does not even have the relevant and necessary technology and infrastructure to harness these products, they are also largely exhaustible, and thus non-renewable.

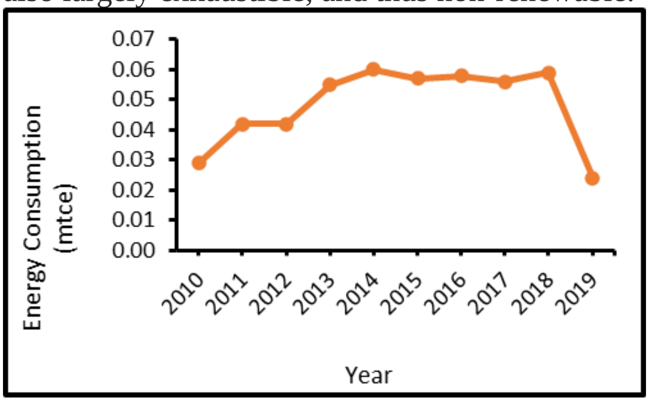

Figure 1: 10-year energy consumption in Nigeria (Adapted from Knoema, 2021)

Furthermore, the use of these fossil fuels degrades environmental quality, with a resultant adverse effect on human, animal, and plant lives. For example, the volume of CO_2 emitted into the atmosphere annually by the utilization of fossil fuels in Nigeria, which can alter ecological balance, is presented in Table 2.

Table 2: Annual CO_2 emissions from the combustion of fossil fuel energy sources in Nigeria

Year	Crude oil (Mt)	Natural Gas (Mt)	Coal (Mt)	Total (Mt)
2009	27.8	16.2	0.1	44.1
2010	37.5	19.3	0.1	56.9
2011	39.7	26.7	0.1	66.5
2012	43.3	27.1	0.1	70.5
2013	54.4	26.4	0.1	80.9
2014	59.5	29.3	0.1	88.9
2015	53.5	28.9	0.1	82.5
2016	56.1	27.9	0.1	84.1
2017	56.7	29.2	0.1	86.0
2018	73.1	31.1	0.1	104.3

Source: IEA (2021)

3.2 The Concept of Biogas

Biogas is a form of gas that is generated from the anaerobic decomposition of organic wastes. The decomposition could be naturally occurring or artificially induced, under controlled conditions. The chart in Figure 2 shows the several by-products of the decomposition of organic waste. From the chart, organic decomposition can occur naturally from decay under water or in the guts of animals; and artificially in an airtight enclosure, usually referred to as a digester.

Biogas has been severally defined based on its

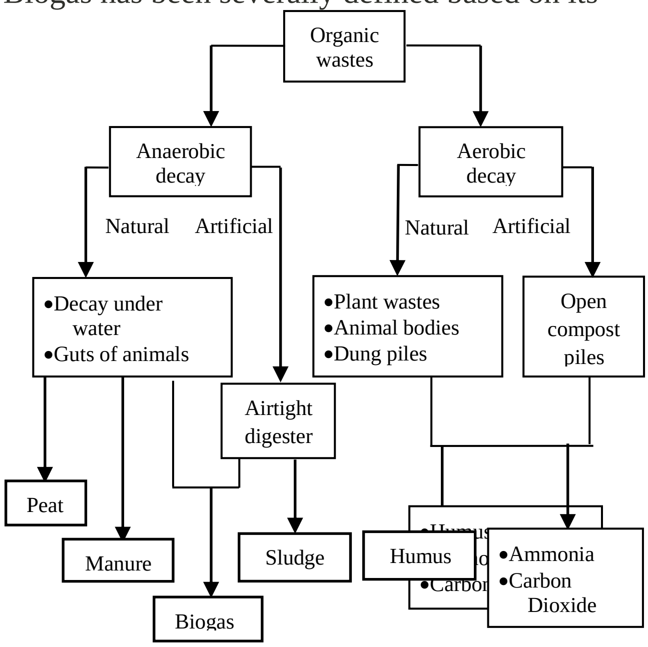

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Figure 2: Decomposition of organic waste into by-products (Adapted from Steadman, 1975)

mode of production. Itodo and Philips (2001) described biogas as "a methane-rich gas that is produced from the anaerobic digestion of organic materials in a biological-engineering structure called the digester". This definition simply suggests that biogas is only produced artificially, which is evidently not the case. Also, GEMET, (2000) says biogas is "Gas rich in methane, which is produced by the fermentation of animal dung, human sewage or crop residues in an air-tight container". This perspective of defining biogas derived from the fact that it is through the controlled (artificial) production that usable biogas is generated. However, GEMET's definition is strictly associated with only a set of organic materials, which are probably the ones in use for biogas generation at the time of his definition, not realizing the potency of the organic matter component of MSW.

Organic matter could be decomposed in the absence of air using physical or chemical processes at high temperature and/or pressure, or the use of microorganisms at relatively low temperatures and atmospheric pressure. Usually, the preferred method depends on the intendment of the decomposition bid and on the relative polluting impacts of the various methods on the environment. However, despite the method used, gas is produced. The gas produced is referred to as biogas, if the process leading to it was based on the action of microorganisms on the organic wastes (Hobson *et al*., 1981). So, in a very strict sense, biogas is a by-product of the biological breakdown, under oxygen-free conditions of organic wastes, such as plants, crop residues, wood and bark residues, and human and animal manure. It is a colourless, relatively odourless, and inflammable gas, composed of methane, carbon dioxide and other gases in trace amounts. The percentage composition of these gases is presented in Table 3. According to Madu and Sodeinde (2001), biogas, which is stable and non-toxic, burns with a blue flame and has a heat value of 4500 – 5000 kcal/m^2 when its methane content is in the range of 60–70%.

Table 3: Percentage composition of the various constituent gases in biogas.

Constituent	Composition (%)
Methane (CH_4)	55 – 75
Carbon dioxide (CO_2)	30 – 45
Hydrogen sulphide (H_2S)	1 – 2
Nitrogen (N_2)	0 – 1
Hydrogen (H_2)	0 – 1
Carbon monoxide (CO)	Traces
Oxygen (O_2)	Traces

Source: Madu and Sodeinde (2001)

3.2.1 Uses of Biogas

Heating, Electricity and Combined Heat and Power (CHP)

Biogas can be converted to thermal energy which is used to heat up the digester. Excess heat can be converted to steam and used for district heating. By combusting biogas in a biogas engine, electrical energy is produced. Combined heat and power (CHP), also known as cogeneration plants use CHP engines and fuel cells to produce electricity and heat from biogas. The heat produced, usually within temperatures of 70 – 90 °C is recirculated though heat exchangers and used to maintain the digesters at their operating temperatures. All the world over, biogas has been variously used for heating purposes and/or electricity generation. In Denmark, over 33 GWh of electrical energy and 55 GWh of heat energy is generated annually from its largest biogas plant (Lemvig, 2016). The excess electricity and heat are sold to the national grid. In the United States, the Columbia Boulevard wastewater treatment plant, produces about 17 million m^3 of biogas per annum and generates 1.7 MW electricity which caters for 40% of its electricity needs (Environmental Services, 2016). The plant also exports 20% of the gas to a nearby industrial facility for process heating. Asia Biogas commenced operation on its biogas plant in Thailand (Bioenergy Insight, 2016). The plant generates 12.3 GWh of electrical energy per annum.

Cooking

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Biogas is an inflammable gas which makes it amenable for use in cooking, also considering that it contains around 60% methane, which is the primary constituent of natural gas. It is widely used for cooking in many Asian countries including India, Thailand, China (MyClimate, 2016; World Bank 2014). Special biogas cookers are developed for this purpose or existing cookers are modified to adapt for using biogas as fuel source. Using biogas for cooking reduces the demand on wood fuels in rural areas, reduce drudgery in rural women among other benefits. In developed countries in Europe and the United States, biogas needs to be upgraded to at least 95% methane before it can be injected into the national gas grid for consumption as fuel for households (The Greenage, 2016).

Transportation
Biogas is a lower-carbon intensity fuel as compared to petrol and diesel (Bilek, 2013). By stripping biogas of impurities and upgrading it to upwards of 95% methane, it can be compressed and used in automobiles designed to run on compressed natural gas (CNG) or liquefied natural gas (LNG). Compressed biogas has been successfully applied to running automobiles in countries such as Sweden, Germany, Switzerland, Iceland, Norway, and Austria (Scarlet *et al.*, 2018; Klackenberg, 2019). Klackenberg (2019), reported that there were 50,330 cars and other small vehicles, 2,618 buses and 1,034 trucks running on biogas in Sweden, in 2019. India tested its first biogas fuelled car in 2014 and bus in 2017 (Gohain, 2014; International Renewable Energy Agency (IRENA), 2017). Papacz (2011) stated that CO_2 emissions can be reduced by 75% - 200% by using biogas as transport fuel.

3.3 Understanding Municipal Solid Waste

The concept of waste has changed from being an unwanted material to a material that has varying degrees of usefulness, depend on who is in possession of it. Currently, there are different perspectives from which waste is described. According to Bailie *et al.* (1997), "for practical purposes, the term waste includes any material that enters the waste management system", where a waste management system refers to organized programs and central facilities established not only for final disposal of waste but also for recycling, reuse, composting, and incineration. They explain that "materials enter a waste management system when no one who has the opportunity to retain them wishes to do so".

The classification of waste follows the various states of matter as gaseous, liquid, and solid, in which it occurs. Ogunbiyi (2001) explained that solid waste is a non-fluid type of waste; and this makes its handling and management relatively difficult, compared to the types of waste that can flow from one location to another, or vaporize. In the view of Kiely (1998), solid wastes are those wastes from human and animal activities including liquid wastes like paints, old medicines, spent oils etc. Thus, it is therefore possible to have solid waste intermixed with liquid waste, even though it is herein considered as strictly non-flowing.

As solid waste does not flow and, therefore, continually remains at its place of generation or deposition until it is physically removed for effective disposal, it poses several problems to the environment and its managers. Some of the problems are the effusion of offensive odours, obstruction of traffic flow, blocking of waterways/drain channels, leading to flooding, destruction of environmental aesthetics and pollution of atmospheric air, with an accompanying adverse effect on public health.

A further classification of solid waste is based on its place of generation. Generally, solid waste collected from domestic, commercial and some industrial (non-hazardous) sources is described as municipal solid waste (Kiely, 1998; Bailie *et al.*, 1997). So, MSW is all non-toxic, non-flowing waste generated from within and around a municipality.

3.3.1 Municipal Solid Waste Generation in Nigeria

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Vol 3, Issue 4, December 2021
Available online at http://www.rsujnet.org/index.php/publications/2021-edition
e- ISSN: 2795-2215

Nigeria is a large country with a correspondingly huge population. As at 2006, the country had a population of 140,003,542 and by 2016, the population was estimated as 193,392,517 (NBS, 2018). The implication of this is the generation of very large volumes of MSW. The current MSW generation status of Nigeria is presented in Table 4, indicating an annual load of over 27 million tonnes. This waste load requires effective and sustainable management strategies to handle

Table 4: Estimated MSW generation rates in the 36 states of Nigeria and the FCT

States in Nigeria	Projected Population as of 2016	MSW Generation (kg/capita/day)	Total Waste Load (kg/day)
Abia	3,727,347	0.46	1,714,580
Adamawa	4,248,436	0.65	2,761,483
Akwa Ibom	5,482,177	0.60	3,289,306
Anambra	5,527,809	0.53	2,929,739
Bauchi	6,537,314	0.19	1,242,090
Bayelsa	2,277,961	0.16	364,574
Benue	5,741,815	0.54	3,100,580
Borno	5,860,183	0.58	3,398,906
Cross River	3,866,269	n/a	n/a
Delta	5,663,362	0.60	3,398,187
Ebonyi	2,880,383	0.44	1,267,369
Edo	4,235,595	0.34	1,440,102
Ekiti	3,270,798	0.71	2,322,267
Enugu	4,411,119	1.03	4,543,453
Gombe	3,256,962	n/a	n/a
Imo	5,408,756	n/a	n/a
Jigawa	5,828,163	n/a	n/a
Kaduna	8,252,366	0.58	4,786,372
Kano	13,076,892	0.56	7,323,060
Katsina	7,831,319	n/a	n/a
Kebbi	4,440,050	n/a	n/a
Kogi	4,473,490	n/a	n/a
Kwara	3,192,893	0.43	1,372,944
Lagos	12,550,598	0.63	7,906,877
Nassarawa	2,523,395	n/a	n/a
Niger	5,556,247	n/a	n/a
Ogun	5,217,716	0.66	3,443,693
Ondo	4,671,695	0.54	2,522,715
Osun	4,705,589	0.54	2,541,018
Oyo	7,840,864	0.51	3,998,841
Plateau	4,200,442	n/a	n/a
Rivers	7,303,924	0.6	4,382,354
Sokoto	4,998,090	n/a	n/a
Taraba	3,066,834	0.34	1,042,724
Yobe	3,294,137	0.32	1,054,124
Zamfara	4,515,427	n/a	n/a
FCT Abuja	3,564,126	0.69	2,459,247
Total	**193,392,517**		**74,606,333**

Sources: Babalola *et al.* (2010), Bichi and Amatobi (2013), Ezeah (2010), Igbinomwanhia *et al.* (2014), Lawal and Gital (2015), Musa *et al.* (2016), NBS (2018), Nnaji (2015), Nwofe (2013), Ogwueleka (2009), & Tsunatu *et al.* (2015).

3.3.2 Energy Potential of Municipal Solid Waste

Oregon Department of Energy (2018) stated that municipal solid waste contains a large volume of biomass, where biomass resources are any plant or derived organic matter available on a renewable basis. This includes agricultural and forestry crops, and animal and municipal wastes. Igoni (2006) investigated MSW in Port Harcourt, Nigeria, and found that 69.3% of the MSW is of organic matter.

Several attempts have been made in different parts of the country to estimate the possible amount of energy obtainable from MSW. Igoni et al (2007) investigated the properties of MSW in Port Harcourt and found an energy content of 7.25 MJ/kg. In their research, Ujile and Lebele-Alawa (2011) studied energy conservation from MSW and showed that about 2.26 MW of electrical energy could be generated daily from waste per city. Lawal and Gital (2015) estimated the calorific value of solid waste in Bauchi at 6.83 MJ/kg. They reported the work of Momoh et al (2010), where the energy content of the solid waste was observed to be 18.43 MJ/kg. They also found that with a combustion power plant operating at 50% efficiency, it was possible to generate 2,923kW of electricity. In Jalingo metropolis, Tsunatu et al (2015) reviewed the possibility of using MSW as alternative source of energy generation and found a net power generation potential of 62,596.80 kW and 151,016.14 kW respectively from bio-chemical and thermo-chemical conversion processes. They state that if all the MSW were converted into energy, instead of being simply discarded, it would be possible to reduce the country's

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dependence on oil and coal by at least three or four percent. Igoni and Harry (2016) estimated that the total energy potential from the AD of MSW generated in urban areas in Nigeria would be 1,013 MW of electricity by 2025.

3.4 The Biogas Imperative

The exploitation of biogas as an alternative energy to the use of fossil fuels is not novel. Melikoglu (2013) assessed the feasibility of electricity and biogas production from the 25 million tonnes of MSW generated annually in Turkey. They explained that by capturing 25% of the 2100 million cubic meters of methane emitted from landfills in Turkey in 2012, it was possible to generate 2900 GWh of electricity or 0.5% of Turkey's annual electricity demand by 2023. There are yet several other such global efforts. Research in the UK showed that as of 2001, from the 18 million tonnes of refuse generated, it was possible to meet 5% of UK's energy requirement. So, from the environmental friendliness of biogas production and the renewability of the energy source, it is convenient to assert that it is a veritable imperative to the pervading current devastating modes of exploitation of non-renewable fossil fuels.

There are biogas plants existing in different parts of the world. As of 2011, China had over forty million biogas plants/systems, after adding about twenty-two million new ones between 2006 and 2010. By 2010, India and Vietnam respectively had 4.3 million and 100,000 biogas plants. This increasing resort to the use of biogas as a viable energy alternative is also seen in Asian countries like Cambodia, Laos, and Indonesia. In Europe, Germany is acclaimed as the pace setter in the biogas production business. As of 2006, the country already had 3500 plants, and aimed at adding about 43,000 new ones up to the year 2020 (Deublein & Steinhauser, 2011).

3.4.1 Nigeria's Biogas Potential

Nigeria generates a considerably high MSW load annually, estimated at over 27million tonnes. Amber et al (2012) reported that around 60% of MSW generated in Nigeria is biodegradable, which means that around 16 million tonnes of organic MSW are generated annually. As a rule of thumb, 100 m^3 of biogas is produced per tonne of organic MSW digested. If 2 kWh of electricity is obtained from 1 m^3 of biogas produced, a total of approximately 30 GWh of electricity will be available for consumption annually from the anaerobic digestion of MSW. If transmission and distribution losses are taken as 20%, using a per capita electricity consumption of 61.5 kWh (CBN, 2014) a total of 390,243 people will be accommodated in the grid. This represents 0.2% of the total energy consumption of the country. The World Bank reports that the optimal throughput of a viable commercial anaerobic digestion plant which uses MSW as feedstock is approximately 100,000 tonnes per annum (Annex 4C.1). From table 4, every state in Nigeria, can have at least one large scale anaerobic digestion plant. Since MSW is a renewable energy source and there are no alternative environmentally sound systems of disposal, such plants when established will not run out of feedstock.

3.4.2 Biogas Initiatives in Nigeria

Biogas research and development in Nigeria started with the establishment of the Sokoto and Nsukka renewable energy centres in 1982. There are quite a few biogas plants in Nigeria, most of which are pilot-scale plants (Akinbomi *et al.*, 2014). The existing plants produce biogas from agricultural waste, animal droppings, abattoir effluent and sewage. Table 5 presents some of the biogas initiatives in Nigeria. In addition to these, in 2019, a 100 kVA biogas plant was built by researchers in the University of Nigeria, Nsukka (UNN), Enugu State.

Table 5: Some biogas initiatives across Nigeria

Location of Biogas Plant	Feedstock	Yield	Use
NCERD/UNN, Achara, Enugu State	Animal droppings, crop residues	10 m^3	Cooking
Ojokoro/ Ifelodun, Agege, Lagos State	Swine slurry	18 m^3	cooking
NAPRI*, Zaria, Kaduna State	Cow dung slurry	20 m^3	
Zaria prison,	Human waste	30 m^3	

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Location of Biogas Plant	Feedstock	Yield	Use
Kaduna State			
Mayflower Secondary School, Ikenne, Ogun State	Cow dung slurry	20 m^3	
Bodija, Oyo State	Cow dung slurry	1500 m^3	cooking
Kutunku farms, Minna, Niger State		124 m^3	Electricity
Federal Univ of Agriculture, Makurdi	Cow dung slurry		Electricity /Experimental

*National Animal Research Production Institute

Sources: Dioha *et al.* (2012), Dahlquist (2013), Igoni (2019)

3.4.3 Potential Barriers to the Adoption of Biogas from MSW in Nigeria

A good MSW management structure and availability of infrastructure are major determinants of the adaptability of biogas from MSW or any other form of waste-to-energy program. Sadly, this is lacking in Nigeria. There is yet any holistic approach to waste handling in the country. Efforts in this regard have focused on only one aspect of the waste management structure – waste collection – which at present is still not efficient. Before putting a biogas from MSW facility in place, feasibility studies require that there is a steady source of feedstock to meet the daily operations of the plant. Where this data is not available, it becomes difficult to estimate the viability of the venture, hence less attractive to investors. Funding is also a major setback for the adoption of biogas from MSW. Setting up conventional biogas plants is a capital-intensive venture which the government is not willing to engage in. Even modular biogas plants are beyond the reach of low-income earners. In developing countries like Tanzania, Ethiopia, India, and Kenya where these are available, the prices are highly subsidised by donor agencies (Rupf *et al.*, 2015). Finally, as biogas from MSW facilities are expensive to install, it is important that users of energy make conscious efforts at efficient utilisation to prevent wastages. This is not what obtains in Nigeria now. A massive re-orientation of the citizenry on efficient utilization of energy will be needed to be embarked upon to bring this about.

4. CONCLUSION

Nigeria is in dire need of an increased energy generation capacity. Every aspect of her national life, including the socioeconomic and infrastructural development, is adversely affected by the inadequacy of its energy generation ability. The frustrating imbalance in the country's energy generation and consumption disposition has laid a terrible burden of underdevelopment on various sectors of the country. This has been shown to be attributable to the continued reliance on fossil fuel-based sources alone. If this situation continues, it will further plunge the nation deeper into harsher energy crises. It has been shown that biogas energy from MSW would be a viable option for additional energy supply in the energy mix of the country, to enhance its current debilitating energy status. Biogas energy generation technology is already globally proven and commercially available in developed countries and is also gaining prominence in some developing countries, with aid from international funding organizations. What is required, is for Nigeria to overcome the inertia of sole dependence on fossil fuel sources and summon the courage to venture into large-scale development of an MSW processing plant for biogas production. Once the country can surmount the challenges of initial installation costs, inadequate MSW management structure and inefficient energy utilization, she is bound to benefit maximally from the energy potential of the MSW generated in the country. This will also present a cleaner environment as obtains in some other parts of the world

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