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Potential of Organic Waste for Biogas and Biofertilizer Production in Nigeria

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With the growing demerits of fossil fuels - its finitude and its negative impact on the environment and public health - renewable energy is becoming a favored emerging alternative. For over a millennium, anaerobic digestion (AD) has been employed in treating organic waste (biomass). The two main products of anaerobic digestion, biogas and biofertilizer, are very important resources. Since organic wastes are always available and unavoidable, too, anaerobic digestion provides an efficient means of converting organic waste to profitable resources. This paper elucidates the potential benefits of organic waste generated in Nigeria as a renewable source of biofuel and biofertilizer. The selected organic wastes studied in this work are livestock wastes (cattle manure, sheep and goat manure, pig manure, poultry manure; and abattoir waste), human manure, crop residue, and municipal solid waste (MSW). Using mathematical computation based on the standard measurements, Nigeria generates about 542.5 million tons of the above selected organic waste per annum. This, in turn, has the potential of yielding about 25.53 billion m^3 of biogas (about 169, 541.66 MWh) and 88.19 million tons of biofertilizer per annum. Both have a combined estimated value of about ₦ 4.54 trillion ($ 29.29 billion). This potential biogas yield will be able to completely replace the use of kerosene and coal for domestic cooking, and reduce the consumption of wood fuel by 66%. An effective biogas program in Nigeria will also remarkably reduce environmental and public health concerns, deforestation, and greenhouse gas (GHG) emissions.

Key words: *Renewable energy, anaerobic digestion, biogas, biofertilizer, organic waste, Nigeria*.

1. Introduction

Biogas technology, also known as anaerobic digestion (AD) technology, is the use of biological processes in the absence of oxygen for the breakdown of organic matter and the stabilization of these materials by conversion to biogas and nearly stable residue (digestate) (Marchaim 1992). Biogas is a mixture of methane (45-75%) and carbon dioxide (25-55%), the actual proportion depending on the feedstock (substrate) used and the processes employed. For biogas to be flammable the methane content must be ≥ 40%. Apart from methane and carbon dioxide, biogas may also contain small amounts (≤ 3%) of impurities such as hydrogen sulphide, ammonia, carbon monoxide, and other gases (Monnet 2003).

Historical evidence indicates that AD is one of the oldest technologies. Even around 3000 BC, the Sumerians practiced anaerobic cleansing of waste (Deublein and Steinhauser 2008). However, the industrialization of anaerobic digestion began in 1859 with a first AD plant sited in Bombay (India). In 1897, an anaerobic digester at Matunga Leper Asylum in Bombay used human waste to generate biogas (Khanal 2008). According to Deublein and Steinhauser (2008), other countries that pioneered the evolution of biogas technology were:

- France, in 1987 the streets lamps of Exeter started running on biogas produced from wastewater;
- China, rural biogas system developed in 1920, while the national program started in 1958;

- Germany, agricultural products were used to produce biogas in 1945.

Today, China is credited as having the largest biogas program in the world with over 20 million biogas plants installed (Tatlidil *et al*. 2009).

According to Deublein and Steinhauser (2008), biogas technology was introduced in Africa between 1930 and 1940, when Ducellier and Isman started building simple biogas machines in Algeria to supply farmhouses with energy. Despite this early start in Africa, the development of large scale biogas technology is still in its embryonic stage in this region, though with a lot of potentials. In Nigeria, the status of biogas technology remains abysmal. The earliest record of biogas technology in Nigeria was in the 1980s, when a simple biogas plant that could produce 425 litres of biogas per day was built at Usman Danfodiyo University, Sokoto (Dangogo and Fernado 1986). About 21 pilot demonstration plants with a capacity range of between $10m^3$-$20m^3$ have been sited in different parts of the country.

The two main products of biogas technology are biogas (fuel) and biofertilizer (fertilizer), and according to Matthew *et al*. (2011) and Adewumi *et al*. (2010), the benefits derived in employing AD in treating organic wastes are:

Benefits for the energy sector:-

- source of renewable (green) energy which leads to a lesser dependency on the finite fossil fuels;
- the use of digestate decreases the use of fossil fuels in the manufacturing of synthetic fertilizer;
- it is carbon dioxide neutral.

Benefits for agriculture:-

- transformation of organic waste to very high quality fertilizer;
- utilization of nitrogen (by plants) from animal manure;
- balanced phosphorus/potassium ratio in digestate;
- homogenous and light fluid slurry;
- AD virtually destroys all weed seeds, thus reducing the need for herbicides and other weed control measures;
- provides closed nutrient cycle;
- treated effluent from AD is a good animal feed when processed with molasses and grains.

Benefits for the environment:-

- reduces emission of greenhouse gases (GHG);
- reduces nitrogen leaching into ground and surface waters;
- improves hygiene through the reduction of pathogens, worm eggs, and flies;
- reduces odour by 80%;
- controlled recycling/reduction of waste;
- reduces deforestation by providing renewable alternative to woodfuel and charcoal;
- biogas burns "cleaner" than woodfuel, kerosene, and undigested biowaste;
- creates an integrated waste management system, which reduces the likelihood of soil and water pollution compared to the disposal of untreated biowastes.

Benefits to the economy:-

- provides cheaper energy and fertilizers;
- provides additional income to farmers;
- creates job opportunities;
- decentralizes energy generation and environmental protection.

Mountainous heaps of open waste dumps have continued to characterize urban centres in Nigeria. Different waste management institutions, saddled with the responsibility of waste management, have continuously failed in their mission. Open waste dumps are sometimes incinerated, thereby releasing toxic fumes which threaten public health. Other fallouts being: odour emission, breeding ground for disease vectors and pathogens, uncontrolled recycling of contaminated goods, and pollution of water sources (Agunwamba 1998). According to FAO (2010), Nigeria has the highest rate of deforestation in the world with 55.7% (9, 587, 577 hectares) of her primary forest lost between 2000 and 2005. 50 million tons of woodfuel is consumed in Nigeria per annum. Records also show that Nigeria ranks number 8 in the world in the methane emission with about 20 billion m^3 of methane emission (13% of world emission). 69% of Nigeria's methane emission actually comes from gas flaring, while 28.8% comes from untreated organic wastes (www.factfish.com). According to Akinbami *et al.* (2001), if biogas displaces kerosene, at least between 357 - 60, 952 tons of carbon dioxide emission will be avoided. Also, the electricity generating sector in Nigeria has been very inefficient with blame always going to insufficient gas supply and reduced water levels at the dam. Biogas can be a big relief here, too. The lack of fertilizers, detrimental effects of synthetic fertilizers to soil chemistry and biology, and the huge amount of foreign exchange invested in the importation of synthetic fertilizers can be drastically reduced by using the digestate of AD instead.

In Nigeria, biogas technology has remained at the level of institutional research work and pilot schemes. Its progress being stunted by ignorance, researches, at universities frequently considered as being too academic, lack in political will, and lack in an adequate coordinating framework.

This study highlights the biogas and biofertilizer potentials from selected organic solid wastes generated in Nigeria with its numerous benefits. The scope of the study is limited to organic wastes from selected livestock (cattle, sheep and goat, pig, poultry, and abattoir waste), human manure, crop wastes, and municipal solid waste (MSW).

2. Materials and methods

The materials and methods employed in this study are as follows:

Data on:-

a. the number of cattle, sheep, goat, pig, poultry in Nigeria, and the total manure they generate per annum (Garba 2010);
b. tonnage of abattoir waste generated per annum in Nigeria (ECN 2005);
c. tonnage of human manure generated calculated using 1.093 x 10^{-3} tons/individual/day (Quazi and Islam 2010) with a population of 130 million (ECN 2005);
d. tonnage of crop residue (waste) generated per annum in Nigeria (ECN 2005);
e. tonnage of municipal solid waste (MSW) generated per annum in Nigeria (ECN 2005).

The following coefficients as deduced from Lil *et al*. (2010); Schnurer and Jarvis (2010); Tatlidil *et al*. (2009); and Rao *et al*. (2000) were used to estimate the amount of biogas derivable from each biowaste: 33 m^3 ton^{-1} for cattle manure, 58 m^3 ton^{-1} for sheep and goat manure, 60 m^3 ton^{-1} for pig manure, 78 m^3 ton^{-1} for poultry manure, 53 m^3 ton^{-1} for abattoir waste, 50 m^3 ton^{-1} for human manure, 60 m^3 ton^{-1} for crop residue (waste), and 66 m^3 ton^{-1} for organic fraction of MSW.

The following coefficients, as given by the Lil *et al*. (2010); Yu *et al*. (2010); Schnurer and Jarvis (2010); Tatlidil *et al*. (2009); and Rao *et al*. (2000), were used to estimate the biochemical methane potential (BMP) of biogas from various biowastes: 56% for cattle manure, 70% for sheep and goat manure, 60% for pig manure, 66% for poultry manure, 60% for abattoir waste, 65% for human manure, 60% for crop residue, and 66% for organic fraction of MSW. The energy potentials of different biogas volumes generated were based on the calorific value of their methane content, while the tonnage equivalents of selected fuels to different estimated biogas volumes were based on their energy potentials.

The MSW presented in this work is actually only its organic fraction, which is 50% of the mass of the total MSW generated in Nigeria.

The coefficients used in estimating biofertilizer yields were based on the fraction of the dry mass portion of each organic waste that is not converted to biogas. According to Dublein and Steinhauser (2008), the dry mass (DM) percentage of fresh organic waste was given as: 25% for cattle manure, 18% for sheep and goat manure, 20% for pig manure, 10% for poultry manure, 15% for abattoir waste, 25 % for human manure, 89% for crop residue, and 30% for organic fraction of MSW. While the volatile solids (VS) percentage (which is the portion of the DM that can be potentially converted to biogas) of the DM were given as 80% for cattle manure, 80% for sheep and goat manure, 75% for pig manure, 70% for poultry manure, 85% for abattoir waste, 84 % for human manure, 85% for crop residue, and 75% for organic fraction of MSW. 60% of VS is the actual fraction taken to be converted to biogas (Burke 2001). Hence, the following formula for computing the potential dry mass of biofertilizer yield was deduced as:

Potential biofertilizer yield (dry) from each organic waste = (DM – VS) + (40% of VS)

DM = **D**ry **M**ass, mass of solid component of organic waste (i.e. organic waste minus moisture content)

VS = **V**olatile **S**olids, portion of DM that can be potentially converted to gas (i.e. dry mass minus mineral content)

3. Results and discussion

Figure 1 shows that 68% of solid biowaste generated in Nigeria came from livestock wastes (manure and abattoir waste), while 15%, 10%, and 7% came from crop wastes, human manure, and MSW, respectively. The total tonnage of biowaste generated per annum was estimated at about 542.5 million (Table 1). This biowaste has the potential of generating 25.53 billion m^3 biogas, with 66% (16.66 billion m^3) coming from livestock wastes alone, while MSW, human manure and crop residue contributed the remaining 5%, 10%, and 19%, respectively (Figure 2 , Table 1).

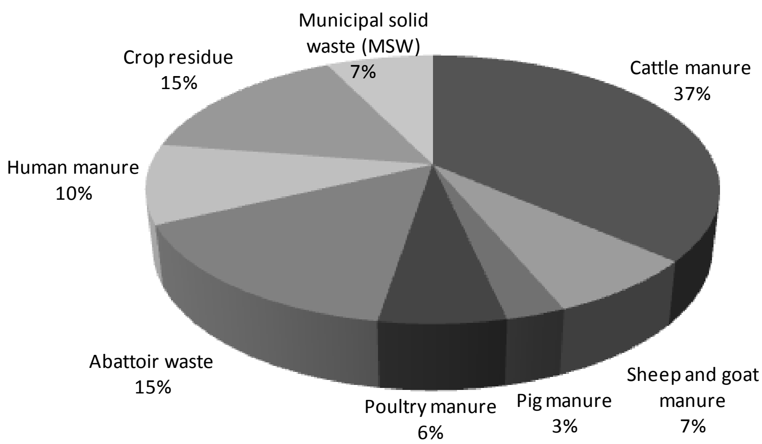

Fig. 1. Sector tonnage percentage distribution of selected organic waste (biomass) generated in Nigeria

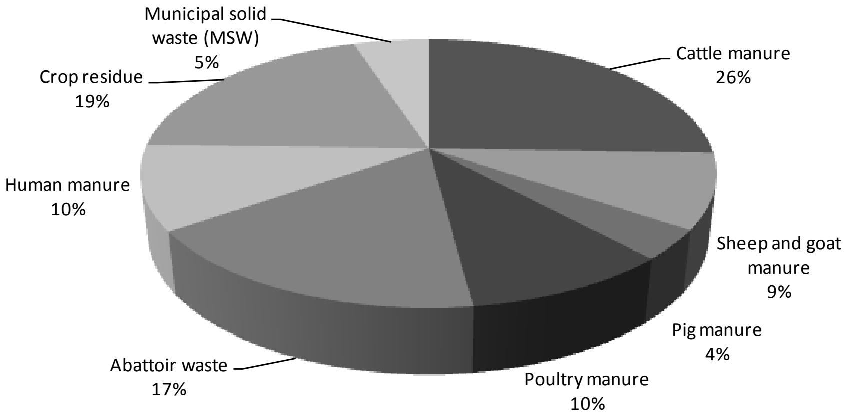

Fig. 2. Sector percentage distribution of potential biogas generation from selected organic waste in Nigeria

Table 1. Potential biogas obtainable from different organic waste (biomass) in Nigeria

Organic waste (biomass)	**Population (millions)**	**Total biomass generated (million tons year^{-1})**	**Estimated biogas potential (billion m^3 year^{-1})**
Cattle manure	21	197.6	6.52
Sheep and goat manure	100.9	39.6	2.3
Pig manure	9.6	15.3	0.92
Poultry manure	112.9	32.6	2.5
Abattoir waste	-	83.3	4.42
Human manure	130	52	2.6
Crop residue	-	83	4.98
Municipal solid waste (MSW)	-	39.1	1.29
Total		542.5	25.53

Table 2. Biomethane potential (BMP) and energy values (based on the calorific value of methane content) of different organic waste (biomass) in Nigeria

Organic waste (biomass)	**Estimated biogas potential (billion m^3 year^{-1})**	**Biomethane potential (BMP) of biogas (billion m^3 year^{-1})**	**Energy potential of biogas (TJ) per annum**
Cattle manure	6.52	3.65	142, 350
Sheep and goat manure	2.3	1.61	62, 790
Pig manure	0.92	0.55	21, 450
Poultry manure	2.5	1.65	64, 350
Abattoir waste	4.42	2.65	103, 350
Human manure	2.6	1.69	65, 910
Crop residue	4.98	3.0	117, 000
Municipal solid waste (MSW)	1.29	0.85	33, 150
Total	25.53	15.65	610, 350

Table 2 shows the biomethane potentials (BMP) of biogas from different organic wastes and their corresponding energy potential values. A total estimated BMP of 15.65 billion m^3 per annum has an energy value of 610, 350 TJ; with livestock wastes alone contributing 10.11 billion m^3 (394, 290 TJ), which is approximately 64.6% of total of potential bio-energy generated from biowaste. The remaining 35.4% came from crop residue, human manure, and MSW.

Table 3 shows the tonnage equivalents of wood fuel, coal, kerosene, liquefied petroleum gas, and liquefied natural gas to different estimated yields of biogas volumes based on their energy potentials. The total biogas potential of 25.53 billion m^3 per annum is equivalent to 41.52 million tons of woodfuel, 24.29 million tons of coal, 14.17 million tons of kerosene, 13.15 million tons of liquefied petroleum gas, and 13.5 million tons of liquefied natural gas, respectively. In comparison, the 16.66 billion m^3 of biogas that came from livestock wastes alone is equivalent to

26.82 million tons of wood fuel, 15.69 million tons of coal, 9.15 million tons of kerosene, 8.5 million tons of liquefied petroleum gas, and 8.72 million tons of liquefied natural gas, respectively, per annum.

Table 4 reveals the potential amount of biofertilizer (dry) yield obtainable from different organic wastes in Nigeria. The total organic wastes evaluated yielded a potential of 88.19 million tons of dry biofertilizer per annum. While the individual organic wastes gave: 25.69, 3.71, 1.68, 1.89, 6.12, 6.45, 36.2, and 6.45 million tons for cattle manure, sheep and goat manure, pig manure, poultry manure, abattoir waste, human manure, crop residue, and MSW, respectively

Table 3. Tonnage equivalents of selected fuels to different estimated yields of biogas volumes (based on their energy potentials) in Nigeria

Organic waste (biomass)	**Estimated biogas potential per annum (billion m^3)**	**Wood fuel equivalent per annum (million tons)**	**Coal equivalent per annum (million tons)**	**Kerosene equivalent per annum (million tons)**	**Liquefied petroleum gas equivalent per annum (million tons)**	**Liquefied natural gas equivalent per annum (million tons)**
Cattle manure	6.52	9.68	5.67	3.3	3.07	3.15
Sheep and goat manure	2.3	4.27	2.5	1.46	1.35	1.39
Pig manure	0.92	1.46	0.85	0.50	0.46	0.47
Poultry manure	2.5	4.38	2.56	1.49	1.39	1.42
Abattoir waste	4.42	7.03	4.11	2.40	2.23	2.29
Human manure	2.6	4.48	2.62	1.53	1.42	1.46
Crop residue	4.98	7.96	4.66	2.72	2.52	2.59
Municipal solid waste (MSW)	1.29	2.26	1.32	0.77	0.71	0.73
Total	25.53	41.52	24.29	14.17	13.15	13.5

Table 4. Potential biofertilizer (dry) obtainable from different organic waste (biomass) in Nigeria

Organic waste (biomass)	**Total biomass generated (million tons $year^{-1}$)**	**Dry mass (DM) of biomass generated (million tons $year^{-1}$)**	**Volatile solids (VS) of DM (million tons $year^{-1}$)**	**Estimated biofertilizer (dry) potential (million tons $year^{-1}$)**
Cattle manure	197.6	49.4	39.52	25.69
Sheep and goat manure	39.6	7.13	5.7	3.71
Pig manure	15.3	3.06	2.3	1.68
Poultry manure	32.6	3.26	2.28	1.89
Abattoir waste	83.3	12.5	10.63	6.12
Human manure	52	13	10.92	6.45
Crop residue	83	73.87	62.79	36.2
Municipal solid waste (MSW)	39.1	11.73	8.8	6.45
Total	542.5	173.95	142.94	88.19

4. Conclusions

The estimated bio-energy potential of 610, 350 TJ per annum from organic waste is equivalent to 169, 541.66 MWh. This is valued at approximately ₦ 1.01 trillion ($ 6.52 billion). About 17% (4.34 billion m^3) of the 25.53 billion m^3 total estimated biogas potential is required to totally displace kerosene and coal as domestic fuel, while 80% (20.42 billion m^3) of this total estimated biogas potential will reduce wood fuel consumption by about 66% (with present consumption rates per annum being approximately 2.37 million tons for kerosene, 12, 000 tons for coal, and 50 million tons for wood fuel). Replacing wood fuel and kerosene as domestic fuel will drastically reduce deforestation, and prevent many ailments and deaths associated with indoor pollution, due to the use of wood fuel and kerosene in domestic cooking. Also from the above computations, Nigeria will be able to generate about 88.19 million tons of dry biofertilizer from biogas technology per annum. This is about 13 times the tonnage of synthetic fertilizer consumed in Nigeria between 2001 and 2010, for which the Federal Government of Nigeria spent ₦ 64.5 billion ($ 410, 828, 025.48) on fertilizer subsidy (FESPAN 2010). This potential amount of dry biofertilizer obtainable is valued at ₦ 3.53 trillion ($ 22.77 billion) per annum. This estimated potential biofertilizer generated by anaerobic digestion per annum will be in excess of domestic demand; hence, a well planned biogas program in Nigeria will serve as a firm base for foreign exchange, and will considerably reduce greenhouse gas emissions.

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Galimybių naudoti bioskaidžias atliekas biodujų ir biotrąšų gamyboje Nigerijoje tyrimas

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Didėjant iškastinio kuro poreikiui ir reikšmingai veikiant aplinką ir visuomenę, atsinaujinantys energijos šaltiniai vertinami kaip palanki alternatyva poreikiams tenkinti. Beveik tūkstantį metų bioskaidžioms atliekoms tvarkyti buvo naudojamas anaerobinis deginimas. Vykstant anaerobiniam deginimui, susidaro du labai naudingi produktai: biodujos ir biotrąšos. Todėl šiame straipsnyje aprašomas galimybių tyrimas, kaip panaudoti Nigerijoje susidariusias biologiškai skaidžias atliekas naudingiems produktams sukurti. Nigerijoje per metus susidaro iki 542,5 mln. tonų bioskaidžių atliekų, iš kurių būtų galima pagaminti 25,53 mlrd. m3 biodujų (apie 169 541,66 MWh) ir 88,19 mln. tonų trąšų. Rezultatai rodo, kad, panaudojus visus biologiškai skaidžių atliekų resursus, būtų galima 66 proc. sumažinti anglies ir medienos poreikį, pakeičiant jį iš bioskaidžių atliekų išgautomis biodujomis. Be to, tai reikšmingai prisidėtų prie poveikio aplinkai mažinimo ir poveikio žmonių sveikatai, miškų naikinimo bei šiltnamio dujų emisijų.