Quantifying the Power Generation Potential of Nigeria’s Selected Agrowaste Biomass

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Abstract—Access to clean energy is crucial for economic development. There is huge gap in the energy demand and supply in Nigeria; and with the country’s growing population, there is need to increase and improve on the country’s energy mix. One of such ways of achieving improved energy supply in Nigeria is through the use of anaerobic digestion (AD) technologies. These technologies are most suited to the rural areas where agricultural activities are the major business, and access to clean energy is limited. Using Buswell’s formula, the yearly methane potential of cattle manure co-digested with maize straw at a ratio of 3:1, on the basis of the organic dry matter (ODM), was calculated as 4.26 x 10⁸ m³, and estimated to give 1846 MW power of electricity. This will mean approximately 50% increase in Nigeria’s current power output. Mesophilic operating temperature was recommended on the basis of improving digester process stability and energy conservation. The AD technologies would convert the abundant agricultural wastes into useable energy and also reduce uncontrolled greenhouse gas emission from landfills.

Keywords—Anaerobic digestion, mesophilic, organic dry matter, landfill, methane, co-digestion

I. INTRODUCTION

Energy plays an important role in the economic development of any country. Energy has been described as a domestic necessity and major factor of production whose cost directly affects the price of other goods and services [1]. Energy affects every aspect of development, including social, economic, political, environmental, health, water, agricultural, industrial, education and other important services that promote the quality of life. While access to clean energy is an enormous challenge facing developing countries, the lack of consistent and adequate supply of it has also been identified as a major barrier to the economic development of developing countries [2].

Nigeria is faced with enormous energy challenge both in the urban and rural communities. The country has an estimated population of 184 million [3]; and 64% of the population live in rural areas [4]. Fuel-wood is the most widely used domestic energy resource in rural communities in Nigeria and constitutes about 90% of the energy used by rural dwellers [5]. It is estimated that Nigeria consumes over 50 million tonnes of fuel-wood annually, a rate that far exceeds the rate of replenishment of the resource [6].

Anaerobic digestion (AD) is a process used to chemically decompose organic matter in the absence of air [7]. When handled properly, decomposition of organic matter produces biogas which is a mixture of methane, hydrogen sulfide and ammonia gasses. Generation of biogas from anaerobic digestion of biomass is a technology with the capacity to produce sustainable energy and reduce the environmental risks associated with manure and waste management. It is considered an efficient renewable energy when cleaned of impurities, and can be used for cooking, lighting, heating and power generation thereby curtailing greenhouse gas (GHG) emission through reduced dependence on fossil fuels. It also generates organic fertilizer. This work seeks to quantify methane and power generation potential of selected agrowaste biomass, through the anaerobic digestion process, in supporting rural energy needs in Nigeria.

II. NIGERIA’S ENERGY RESOURCES AND STATE OF POWER GENERATION

The energy supply in Nigeria is derived from oil, natural gas, coal, biomass and renewable energy sources. Despite the huge energy resources, there is still a huge gap between the resource potential and development. Nigeria has been faced with lingering energy crisis. Although Nigeria has a growing population of more than 179 million, it generates less than 4,000 megawatts (MW) of electricity annually [8]. Consequently, scarcity of sufficient and reliable electricity is severely restricting economic growth and development.

Though a number of national energy policies and strategies exist, which are aimed at improving energy availability, supply and efficiency, availability and access to clean and affordable energy in Nigeria is still a huge challenge. Rural areas have little access to conventional energy such as electricity due to difficult terrain [6]. Consequently, the sale of fuel-wood and charcoal has become widespread in the unorganized private sector. The absence of reliable energy supply had negatively affected the social life of rural dwellers, and also left their economic potentials untapped. Table 2 shows installed and operational capacities of power generating plants in the country. A huge gap exists between the installed and operational capacities of the power plants as shown in Fig 1.
III. NIGERIA’S BIOMASS POTENTIAL

Biomass consists of organic materials of plant or animal origin, including, but not limited to dedicated energy crops, agricultural crops and trees, agricultural wastes, food and fibre crop residues, biobased component of municipal and industrial waste, and other non-fossil organic material [9]. However, it has been affirmed that converting the huge quantities of biomass resources, mostly in the form of agricultural residues and wastes, to energy production could potentially increase the energy supply thereby increasing Nigeria’s energy mix and balance [10]. Moreover, there are also environmental benefits of reducing greenhouse gas emissions by generating energy from biomass, and improved supply to rural areas [11].

Agricultural crops production data in Nigeria is as presented in Table 2 while the animal waste production and corresponding biogas potential is presented in Table 3. However, there are discrepancies in the figures released by the National Bureau of Statistics (NBS) and National Programme for Food Security (NPFS). Since statistical activities in Nigeria are not well coordinated and to date, as each agency produces statistical data on the basis of its internal needs [12], there are no standard concepts, classifications and specifications that are commonly used by different agencies. Subsequently, there could be significant problems of coherence and comparability. Nonetheless, it can be assumed that agricultural production output lies within the figures quoted by both the National Agricultural Sample Survey (NASS) and NPFS.

Table 2 Production data for selected major agricultural crops. Country-level production estimates (in ‘000 MT)

<table>
<thead>
<tr>
<th>Crop</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maize</td>
<td>9,113.71</td>
<td>7,338.44</td>
<td>9,302.60</td>
<td>8,878</td>
<td>8,695</td>
<td>8,423</td>
</tr>
<tr>
<td>Rice</td>
<td>3,373.52</td>
<td>3,540.94</td>
<td>4,601.60</td>
<td>4,613</td>
<td>5,433</td>
<td>4,823</td>
</tr>
<tr>
<td>Wheat</td>
<td>34.9</td>
<td>165</td>
<td>100</td>
<td>80</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td>234.43</td>
<td>426.59</td>
<td>572.4</td>
<td>493</td>
<td>650</td>
<td>518</td>
</tr>
</tbody>
</table>

(Source FAO 2015; IFPRI, 2016)
IV. THE ANAEROBIC DIGESTION PROCESS AND SYSTEM DESIGN CONSIDERATIONS

Anaerobic digestion (AD) is the consequence of a series of metabolic interactions among various groups of microorganisms. The process occurs in three stages: hydrolysis, acidogenesis and methanogenesis, with hydrolysis considered generally as the rate limiting ([13]; [14]. The hydrolysis stage degrades both insoluble organic material and high molecular weight compounds such as lipids, polysaccharides, proteins and nucleic acids into soluble organic substrates. Products of the hydrolysis stage are further split during acidogenesis, which is the second stage of the anaerobic digestion process [15]. The second stage yields FVA alongside ammonia, CO$_2$, H$_2$S, and other by-products through the action of acidogenic bacteria. In the third stage, methane is produced by bacteria called methanogens. This can be achieved by means of cleavage of acetic acid molecules to yield carbon dioxide and methane, or as a result of the reduction of carbon dioxide with hydrogen [16].

Important design considerations in the AD process include organic concentration and temperature, loading rate, hydraulic and solid retention times. Other factors such as pH, nutrient availability, mixing, pretreatment, and feedstock also have profound effect on biogas yield.

Strength of the influent and operating temperature greatly affect the economics and feasibility of anaerobic treatment. Influent with strong COD yields higher methane production. Similarly, the temperature of anaerobic digestion represents one of the most important parameters in the anaerobic digestion for the production of biogas. It has been reported that thermophilic AD (55–70 °C) has merits over mesophilic ones (between 30 and 38 °C) as a result of its fast operation rates and higher-load bearing limit [17].

The effect of temperature of anaerobic digestion on microbial community, stability and kinetic processes have been reported by several researchers [18], [19]. Decreased microbial growth, utilization of substrate rate and the generation of biogas during anaerobic digestion processes of lower temperatures were observed [19]-[21].

The organic loading rate is the amount of volatile solids (VS) that is fed into an anaerobic digester per day under what is known as a continuous feed process. OLR can be expressed as OLR (kg VS/m3/d) [17]. Bacterial inhibition often occurs in the AD due to higher organic loading rate. This often prompts higher hydrolysis and acidogenesis bacterial action than methanogenesis bacterial movement in the AD system and thus increases the VFA production, which in the end prompts an irreversible fermentation and this results in the decline of pH of the digester [17].

Hydraulic Retention Time (HRT) is the time required to complete degradation of organic matter. This is connected with the microbial development rate which itself depends upon the process of organic loading rate (OLR), substrate composition and temperature. There are two key retention times. The first time is the hydraulic retention time (HRT) which is the average time that the input slurry spends inside the digester [17], [22]. The second time is the solid retention time (SRT), which is referred to as the average time that microorganisms (solids) spend in the digester. A longer retention time incurs more cost as it requires digesters with large volumes while short retention times may bring about washout of the active bacterial population.

pH is a very essential factor in the development of microbes in anaerobic digestion processes. Several authors have reported different ranges for pH that are suitable for AD. Generally, the optimal pH of a digester lies between 6.5 and 7.5 [17], [23]. It was shown that if the pH value decreases to 5, the gas production is significantly affected as the population of cellulytic bacteria [24]. The production of volatile fatty acids during the initial phases of the process tends to depress the pH but further reaction between CO$_2$ and H$_2$O tends to restore the neutrality of the solution [25]. In addition to this mechanism, the overall effect of the pH can be optimized by adding sufficient alkalinity to the solution (3000 mg/l) [7].

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**Table 3. Animal waste production in Nigeria and potential biogas output, 2010**

<table>
<thead>
<tr>
<th>Type</th>
<th>Production</th>
<th>Dry matter production kg/head/day</th>
<th>Amt of dry matter produced per yr kg</th>
<th>Fraction recoverable</th>
<th>Amount of dry matter available per yr kg</th>
<th>m$^3$/kg dry matter**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>18,871,339</td>
<td>2.86</td>
<td>1.97x10$^9$</td>
<td>0.3</td>
<td>5.91x10$^9$</td>
<td>0.2</td>
</tr>
<tr>
<td>Goat</td>
<td>65,651,252</td>
<td>0.552</td>
<td>1.32x10$^9$</td>
<td>0.4</td>
<td>5.29x10$^9$</td>
<td>0.25</td>
</tr>
<tr>
<td>Pig</td>
<td>6,040,820</td>
<td>0.661</td>
<td>1.457x10$^9$</td>
<td>1.0</td>
<td>1.457x10$^9$</td>
<td>0.56</td>
</tr>
<tr>
<td>Sheep</td>
<td>37,422,554</td>
<td>0.329</td>
<td>4.493x10$^9$</td>
<td>0.3</td>
<td>1.348x10$^9$</td>
<td>0.25</td>
</tr>
<tr>
<td>Chicken</td>
<td>101,676,710</td>
<td>0.043</td>
<td>1.596x10$^9$</td>
<td>1.0</td>
<td>1.596x10$^9$</td>
<td>0.28</td>
</tr>
<tr>
<td>Duck</td>
<td>9,553,911</td>
<td>0.051</td>
<td>0.177x10$^9$</td>
<td>0.9</td>
<td>0.159x10$^9$</td>
<td>0.56</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>15.76x10$^9$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source: Simonyan and Fasina, 2013)
Mixing is an important parameter for the operation of the AD process. It plays a vital role towards achieving uniformity in the concentration of substrate, the temperature of the reactor, and environmental conditions in order to minimize the possibility of scum formation and deposition of solids [26]. Mixing is used for the purpose of maintaining the temperature and substrate concentration uniform and in preventing scum formation and deposition [2]. However, intensive mixing results in an increase in retention time because the bacteria are not in contact long enough with the substrate [27].

Substrate pretreatment is aimed at increasing the surface area of the substrate for enhanced microbial attack. It is also used to reduce crystallinity of lignocellulosic materials and particle size of the material so as to increase the specific surface area and consequently reduce the level of polymerization. It is reported that smaller particle size can increase the surface area per unit volume of feedstock in order to enhanced anaerobic degradability [28]-[30]. It increases the surface area available for adsorption of hydrolytic enzymes and thereby enhances biogas production. However, excessive particle size reduction could ever-stimulate the rate-limiting hydrolysis stage, leading to the accumulation of ammonia and VFAs which could affect the activities of methanogens and negatively affect the digester performance [31].

V. METHODS FOR ESTIMATING METHANE YIELD OF AGRICULTURAL WASTES

Different biomass feedstocks have different methanogenic potential, which is a function of their inherent degradability and carbon-oxidation state [32]. This implies that the amount of biogas generated, and its methane content, depends on the characteristics of the feedstock. However, it is difficult to describe in detail the complexity of waste (biomass) composition, but good analyses can be made from bulk chemical process [32].

The Biochemical Methane Potential (BMP) tests are used to expose which types of substrate, from a variety of sources, have the highest biochemical potential [33]. In addition, BMP tests are used to estimate optimum ratios between co-substrates when co-digestion is intended [34]. Although the experimental methane yields are lower than the theoretical, especially due to difficulty in degrading lignocellulosic substances, the theoretical methane potential is much accepted to give an indication of the maximum methane production from a waste biomass [33]. As reported, the conventional BMP test is generally criticized to be time and resource consuming, although it is simple, repeatable and cheap [35].

Several methods exist for the estimation of BMP of feedstock [33]. Examples of the approaches involve the use of empirical relationships on the biochemical and chemical oxygen demand (COD). Others are based on elemental composition of the material, and the organic fraction composition. However, these methods, the authors reported, do not provide the kinetic parameters of the process.

Often, COD is used to estimate BMP, but this method suffers from some inconsistencies. This is because, in COD measurement, a total oxidation of organic matter is made, and therefore biomass recalcitrance and contribution of non-convertible lignin are not considered [36]. This results in the over-estimation of the BMP, but the condition is not significant when dealing with pure substances (e.g. sugars). However, the organic dry matter content of the waste biomass can also be used to estimate the BMP in line with the Buswell formula ([33], [36], [37]). In this study, therefore, only the organic matter contents of the waste biomass is assumed to be converted ultimately to methane.

VI. ESTIMATING YEARLY METHANE YIELD FROM SELECTED AGRICULTURAL WASTE PRODUCTION IN NIGERIA

The yearly methane yield of cattle manure co-digested with maize straw is thus estimated. Maize crop is widely and abundantly grown in all regions of Nigeria, and the straw is easily accessible. Maize straw contains high carbon content which makes it suitable as co-digestion substrate [38]. To balance the C/N ratio in co-digestion, substrates combination of 3:1 (cattle manure to maize straw) on the basis of their dry organic matter (ODM) is recommended [39].

According to Buswell’s formula, the theoretical yield of component products from digestion can be predicted from equation 6.1.

\[ C_nH_{a}O_bN_c + \left( \frac{n - \frac{a}{4} - \frac{b}{2} + \frac{3c}{4}}{2} \right) H_2O \rightarrow \left( \frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8} \right) CH_4 + \left( \frac{n}{2} - \frac{a}{8} + \frac{b}{4} + \frac{3c}{8} \right) CO_2 + cNH_3 \]  

From Table 3

Yearly production of dry cattle waste (Solids Content)  
\[ 1.97 \times 10^{10} \text{kg} \]  
Assuming 62% ODM [43]

Yearly cattle waste ODM  
\[ = \frac{62}{100} \times 1.97 \times 10^{10} \text{kg} = 1.22 \times 10^{10} \text{kg} \]  

Yearly cattle waste ODM  
\[ = \frac{62}{100} \times 1.97 \times 10^{10} \text{kg} = 1.22 \times 10^{10} \text{kg} \]

At 3:1 co-digestion with maize straw, it implies that \( \frac{1}{3} \) (ODM) equivalent of maize straw is required for co-digestion with the cattle ODM,

\[ \frac{1}{3} \left( 1.22 \times 10^{10} \right) \text{kg = ODM equivalent of maize straw} \]

But dry maize straw is 72% ODM [43],

\[ \text{Approximate amount of dry maize straw required for co-digestion} \]

\[ \approx \frac{1}{3} \left( 1.22 \times 10^{10} \right) \times 0.72 = 2.93 \times 10^9 \text{kg} \]

Carbon content in the cattle waste ODM = 45.37% ODM [40]
\[
\text{V}_{30^\circ \text{C}} = \frac{(1 \text{ mol})(0.082057 \text{ atm-L/mol-K})(273.15+30)\text{K}}{1 \text{ atm}} = 24.88 \text{ Litres}
\]

16 g \(\text{CH}_4\) = 24.88 Litres

1 kg \(\text{CH}_4\) = \(\frac{24.88}{0.016}\) = 1555 Litres

2.97x10^9 kg \(\text{CH}_4\) = 1555 Litres x 2.97x10^9 = 4.62x10^{12} \text{ L} \(\text{CH}_4\)

= 4.62x10^9 \text{ m}^3 \(\text{CH}_4\)

\(\because\) yearly methane volume = 4.62x10^9 \text{ m}^3 \(\text{CH}_4\)

VII. ENERGY QUANTIFICATION OF METHANE YIELD

But 1 Watt = 1 Joule/sec

1 Wh = \(\frac{1 \text{ joule}}{\text{sec}}\) x 60 \(\text{sec}\) x 60 \(\text{min}\) x 1 h = 3600 Joules

1 KWh = 3600 Joules x 1000 = 3.6 MJ

\(\therefore\) 3.6 MJ = 1 KWh

But thermal value of methane = 36 MJ/m^3 [44]

This implies that 1 m^3 of \(\text{CH}_4\) yields 36 MJ = 10KWh

\(\therefore\) 4.62x10^9 m^3 \(\text{CH}_4\) yields 4.62x10^9 x 10KWh = 4.62x10^{10} \text{ KWh}

But yearly methane volume = 4.62x10^9 m^3 \(\text{CH}_4\)

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But yearly methane volume = 4.62x10^9 m^3 \(\text{CH}_4\)

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But yearly methane volume = 4.62x10^9 m^3 \(\text{CH}_4\)

\(\therefore\) 4.62x10^9 m^3 \(\text{CH}_4\) yields 4.62x10^9 x 10KWh = 4.62x10^{10} \text{ KWh}

VIII. CONCLUSION

There is potential for Nigeria to boost its energy mix and meet the growing energy demands through the use of anaerobic system technology. Agricultural waste biomass represents a huge potential resource towards actualizing the needs of the country. Though little attention has been paid to energy generation in this regard, this work has shown that, if well harnessed, energy from agrowaste biomass resources can substantially enhance the energy output of the country. This will be particularly useful in the rural communities where the major business is agriculture, and large quantities of agrowaste are generated and wasted annually.

REFERENCES


  nigeria-country-fact-sheet


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