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Availability and Energy Generation Potential of Cattle Rumen Content collected from Vegetable Market Abattoir in Benin City, Nigeria

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ABSTRACT: Anaerobic digestion (AD) is a proven technology for treating biomass materials with a view of producing bioenergy and recovering nutrients. Cattle rumen content (CRC) is an example of a waste biomass material that can be a viable feedstock for AD process. This paper accesses the availability and energy generation potential of cattle rumen content (CRC) collected from vegetable market abattoir in Benin City, Nigeria for a ten-year data of slaughtered cattle in Nigeria. Data obtained revealed that an average 99581.303 Metric tons of dry matter from CRC is generated per annum and with a theoretical biomethane yield of 444.90 ml/gVS can potentially generate 420 GW (gigawatts) in form of biomethane annually in Nigeria through the AD process. When compared with other renewable energy sources in Nigeria, it potentially meets 6.44 % supply from other renewable energy sources, and exceeds energy currently being generated from wind and solar sources combined. Anaerobic digestion if deployed is an effective technology to harness the potential that CRC presents Nigeria as a country for affordable and clean energy (SDG 7), clean water sanitation and sustainable communities (SDG 6 and 11), and zero hunger (SDG 2) through soil nutrient enhancement.

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Human development over time has been dependent on several factors. One of such important factors is energy which is broadly classified according to source into renewable and non-renewable. Most of the energy needs globally are supplied from non-renewable sources such as fossil (crude oil, gas, coal, etc) (Rashed et al., 2018). The continued use of fossil-based fuels to meet energy demands has led to depletion in its reserve and complimentary environmental challenges (Andri *et al*., 2017). There is a great deficiency in energy supply across Nigeria as a nation with fuel wood the oldest and most common energy source for heating and cooking in Nigeria (Momodu, 2013; Oyedepo, 2012). Over 70% of Nigerians in the rural communities heavily depend on fuel wood as an energy source for cooking and heating purposes (Ajieh et al., 2021). As a response to these challenges, biogas has been identified as a possible renewable source of energy for both heating and electricity generation (Andri *et al.*, 2017; Jingura and Matengaifa, 2009). This will certainly contribute in no small measure to socioeconomic development and with commensurate mitigation of environmental concerns. Biogas is produced by biologically decomposing organic materials such as municipal, industrial, and agricultural wastes under anaerobic conditions. This is a technology known as anaerobic digestion (AD). It is a proven technology where a

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consortium of microorganisms degrade organic material (known as biomass) in the absence of oxygen to produce methane-rich gas known as biogas (Jain et al., 2015; Ward et al., 2008). Biogas is a mixture of gases comprising mainly methane (48-70%), carbon dioxide (30-41%), and traces of hydrogen sulfide, ammonia, hydrogen, nitrogen, and carbon monoxide (Andri et al., 2017; Jain et al., 2015; Njuguna et al., 2018; Ward et al., 2008). Biogas presents a couple of advantages such as high methane content which makes it a comparatively clean fuel (Jingura & Matengaifa, 2009). Biomass originates from organic matter (animals or plants) ranks fourth globally as an energy source and provides 14% of the world's energy needs. It accounts for 67% of total energy consumed in Africa (Jingura & Matengaifa, 2009; Njuguna et al., 2018). Biomass from animal waste has been studied by various researchers as feedstock and found efficient in producing biogas from AD process (Andrade et al., 2016; Cuetos et al., 2017; Risberg et al., 2017). The rumen compartment of a cattle's stomach contain partly digested grasses that have been acted upon by microorganisms (BM et al., 2019). These partially digested grasses considered as cattle rumen content (CRC) are extracted and discarded when these cattle are slaughtered, increasing waste generation and pollution to the immediate environment and nearby water bodies. This poses an environmental problem and consequently necessitates the need for proper management. This is a common occurrence as cattle are slaughtered daily to meet the demand for beef meat. Nigeria's annual beef consumption is over 360,000 tons, and this accounts for over half of the beef consumed in West Africa (Vanguard Newspaper, 2019). This stunning figure implies corresponding huge waste generation as most of this demand is met locally with minimal importation (Vanguard Newspaper, 2019). Nigeria's energy demand is expected to be on the increase because of the annual population increase. Between energy supply sources and consumption points, an average of about 824,126 TJ is lost annually. Thus, there is a need to improve on these energy supply statistics and possibly bring the generation closer to the consumption point. This is what adopting anaerobic digestion simply offers while addressing in some sense, potential environmental pollution challenges. This paper attempts to quantify CRC generation in Nigeria and evaluate its potential for energy generation. This is to encourage its adoption as feedstock for AD plants and consequently, waste management towards a cleaner environment. Hence, the objective of this research was to assess the availability and energy generation potential of cattle rumen content (CRC) collected from Vegetable market abattoir in Benin City, Nigeria using a ten-year data of slaughtered cattle in Nigeria

MATERIALS AND METHOD

Data collection and calculation: This study was carried out in a Vegetable market abattoir located in Benin City, Nigeria. The average mass of CRC per cattle was determined by obtaining the mass of partially digested plant materials from the rumen compartment of ten (10) freshly slaughtered cattle and these partially digested materials termed as cattle rumen content were, weighed and recorded. The average mass of these materials (CRC) was determined. This average mass of CRC per cattle as obtained from this study, with the reported number of cattle slaughtered per annum in Nigeria as reported by the Food and Agriculture Organisation (FAO) was used to determine the amount of CRC generated annually.

Cattle slaughtered and CRC production in Nigeria: Nigeria is the highest consumer of beef (meat from cattle) in West Africa (Vanguard Newspaper, 2019). This directly translates to the huge number of slaughtered cattle in the country as most of the demand is mainly met locally with a few imports. The data presented in Table 1 gives the cattle slaughtered annually in Nigeria for a ten (10) year duration as reported by Food and Agriculture Organization (FAO 2019). The sizes and live weight of slaughtered cattle vary, depending on factors such as species, age, mode of feeding, etc. however, the average mass of CRC in the rumen as obtained from this study is 12.19±2.68 kg/cattle for the samples examined.

Calculation of biogas potentials and energy value: The theoretical biomethane yield (TBY) and theoretical methane yield (TMY) in ml/gVS were determined theoretically using elemental compositions (C, H, N, O, S) obtained from elemental studies and the Buswell's equation (Equations 1 to 4) (Zhao et al., 2019). The energy value per year was estimated using the biomethane production per annum and methane energy value of 37.78 MJ/m^3.

$$C_nH_aO_bN_c + \left(n - \frac{a}{4} - \frac{b}{2} + \frac{3c}{4}\right).H_2O \rightarrow \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4} + \frac{3c}{8}\right).CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4} - \frac{3c}{8}\right).CH_4 \quad (1)$$

$$TBY = \frac{22415.n}{12n+a+16b+14c} \quad (2)$$

$$TMY = \frac{22415.\left(\frac{4n+a-2b-3c}{8}\right)}{12n+a+16b+14c} \quad (3)$$

$$\text{Methane content } (\%) = \frac{TMY}{TBY} = \frac{1}{2} + \frac{a-2b-3c}{8n} \quad (4)$$

Proximate analysis: The total solids (TS), volatile solids (VS), pH, and total ammonium nitrogen (TAN) properties of the CRC were determined according to standard methods (APHA, 2015).

Ultimate (elemental) analysis: Elemental composition (C, H, N, S, O) of CRC was determined according to the (Njuguna et al., 2018) using an element analyzer (Flash 2000 CHNS-O analyzer fitted with an autosampler).

RESULTS AND DISCUSSION

Cattle rumen content production: The amount of CRC (wet basis) produced in Nigeria was calculated using the number of cattle slaughtered, and the average weight of biomass from the rumen compartment of the sampled cattle. This was estimated for the ten years under consideration and presented in Table 1. Also, the effluent from the anaerobic digestion process known as digestate has been established to be resourceful organic fertilizer (Koszel and Lorencowicz, 2015; Ndubuisi-Nnaji et al., 2020; Pivato et al., 2016). So, the production of biogas from CRC will significantly lead to the production of huge quantity of digestate and consequently production of organic fertilizer.

Table 1: CRC generated in Nigeria for ten years (FAO, 2019)

Year	Heads per annum	Average mass of CRC (kg) per annum
2010	16,577,962	210,208,558
2011	19,041,270	241,443,304
2012	19,206,928	243,543,847
2013	19,374,029	245,662,688
2014	19,753,249	250,471,197
2015	20,184,763	255,942,795
2016	19,884,104	252,130,439
2017	20,057,095	254,323,965
2018	20,275,529	257,093,708
2019	20,664,069	262,020,395

Theoretical (biogas and methane) potential of CRC: Table 2 shows the physiochemical properties and elemental composition (i.e. the proximate and ultimate analyses) of CRC. The pH is slightly acidic with high dry mass (40.27%) and volatile solid content of 90.93 (% TS). The breakdown of carbohydrate, lipids, and protein largely determine the nitrogen content of the feedstock, and this nitrogen content is highly needed by the mircrobes as well as it determines the C/N ratio (Karki et al., 2021).

Table 2: The proximate and ultimate analysis of cattle rumen content

Property	Value
pH	4.49 ±0.057
TS (%)	40.27 ±4.437
VS (% TS)	90.93 ±0.205
Carbohydrates (%)	14.74 ±2.816
Lipids (%)	2.35 ±0.494
Crude proteins (%)	4.83 ±0.879
Moisture Content (%)	59.72 ±4.437
Ash Content (%)	3.65 ±0.388
COD g/l	1.39 ±0.112

The structural carbohydrate properties of some grasses and CRC are presented in Table 3. Biomass with high values make them the less preferred choice for AD purposes. However, the lignin value of CRC is significantly less compared with other grasses as reported by (Waliszewska et al., 2021) in Table 3. Lignin is an amorphous heteropolymer abundantly found in the cellular walls of most plant materials consisting of phenylpropane units held in place by linkages to give plants structural properties such as support, resistance against microbial attack, impermeability, and oxidative stress (Hendriks & Zeeman, 2009). From Table 3, *Phalaris arundinacea L*. and P*hragmites australis (Cav.) Trin. ex Steud* have average values of 15.42% and 21.99% of lignin content representing the least and highest values respectively. The significant difference in the lignin content between these grasses and CRC clearly suggests that a significant breakdown of lignin has taken place while the grass was in the rumen of the cattle.

Table 3: Structural carbohydrate properties of some grasses and cattle rumen content

Grass Species	Cellulose (%)	Lignin (%)	Hemicellulose (%)
**Phalaris arundinacea L.*	38.68 ± 0.01	15.42 ± 0.01	31.71 ± 1.46
**Phragmites australis (Cav.) Trin. ex Steud*	35.05 ± 0.14	21.99 ± 0.15	30.27 ± 0.15
**Dacylis glomerata L.*	37.71 ± 0.41	19.33 ± 0.05	31.48 ± 1.13
**Arrhenatherum elatius*	35.46 ± 0.20	17.54 ± 0.15	33.17 ± 0.25
**Bromus inermis Leyss.*	35.6 ± 0.51	16.5 ± 0.60	33.71 ± 1.15
**Agrostis capillaris L.*	38.29 ± 0.18	20.48 ± 0.14	31.08 ± 0.39
**Calamagrostis epigejos L. (Roth)*	35.35 ± 0.19	20.96 ± 0.09	33.66 ± 0.9
**Agropyron repens L.*	33.38 ± 1.35	18.76 ± 0.19	30.84 ± 0.84
**Anthoxanthum odoratum L.*	35.18 ± 0.28	17.68 ± 0.04	34.31 ± 0.20
**Holcus lanatus L*	36.43 ± 0.40	17.18 ± 0.16	32.57 ± 0.32
**Corn stover	40.12 ± 1.20	6.10 ± 0.63	32.84 ± 1.84
CRC	43.18 ± 0.17	12.80 ± 0.22	34.61 ± 0.11

All (*) were sourced from (Waliszewska et al., 2021) and (**) from (Li et al., 2015)

The elemental analysis result is presented in Table 4. This was used to derive the empirical equation of the substrate (CRC) as $C_{17.45}H_{31.62}O_{12.84}N$. Buswell's equations (Equations 1-4) were used to estimate the theoretical biogas yield (TBY) as 850.12 ml/gVS and methane yield (TMY) of 444.897 mL/gVS accounting for approximately 52.20% methane content in the biogas. This analysis gives information on the potential CRC possesses as feedstock theoretically. The C/N ratio is also an important factor in determining the stability of microbes in the system as C and N content depicts the nutrient available to microbe (Njuguna et al., 2018). A C/N ratio of 15-30 has been reported to be optimal for different AD systems with the exception of systems with wood as feedstock (Wang et al., 2018).

Table 4: Ultimate analysis of cattle rumen content

Property	Value (%)
C	44.58
H	6.98
O	43.70
S	1.76
N	2.98
C/N (g/100g)	15.0

Biomethane and energy potentials in Nigeria: The data presented in Table 5 shows the annual potential biomethane and bioenergy production from CRC in Nigeria for a ten-year duration. The average annual theoretical biomethane production and net annual energy production are 36,365,499.40 (m^3 CH_4/annum) and 1,373,888,567.26 (MJ) (384.689 x 10^6 kWh) respectively. (Ibrahim et al., 2022) studied the biomethane potential and physiochemical characterization of cassava vinasse from an ethanol distillery to establish its potential for bioethanol production. They reported that cassava vinasse has a potential of 247.10 Nml/gVS which was determined experimentally at 28 ^oC. Also, different agro waste were studied to establish their different biomethane potential (Prabhudessai et al., 2013). The biomethane at 4 g initial VS/l for coconut oil cake, grass from lawn cutting, and cashew apple waste were 383 ml/gVS, 256 ml/gVS and 64.6 ml/gVS respectively. (Armah et al., 2019) reported the biomethane potential of sugarcane bagasse and corn silage at 25 ^oC and 35 ^oC. they set-up digesters in the order of Biodigester A1 contained an inoculum and activated sludge only; A2, contained an inoculum with activated sludge and sugar wastewater; B, comprised of an inoculum, activated sludge, sugar wastewater and corn silage and C, contained an inoculum, activated sludge, sugar wastewater and sugarcane bagasse. From their study, the difference in biogas yield for the two temperatures were reported as follows: B>A2>A1>C for a 35-day retention time. (Matassa et al., 2020) explore the biomethane potential of different parts of industrial hemp. From their study, they reported the highest potential was obtained with the raw fibers (422 ± 20 mL/gVS), while the hurds (unretted), making up more than half of the whole hemp plant dry weight, showed a lower BMP value of 239 ± 10 mL/gVS. Currently, in the singeing of slaughtered cattle, wood or domestic cooking gas is being used. However, this can be substituted with the biogas produced from CRC and further deployed for domestic heating. A huge number of locals across Nigeria use wood for cooking and heating purposes. In 2016, Time newspaper reported that many Nigerian women suffer ailments resulting from firewood usage (Olugboji, 2016). A World Health Organization (WHO) study shows "over 98,000 Nigerian women die annually from the use of firewood. If a woman cooks breakfast, lunch, and dinner, it is equivalent to smoking between three and 20 packets of cigarette a day" (Olugboji, 2016; Vanguard Nigeria, 2013). On cooking with firewood, Vanguard Nigeria puts it that "The death from this sector contributes to 10 percent of global annual death and it is bigger than tuberculosis, HIV and AIDS and malaria combined, and it is only killing women''. Rural communities in Nigeria has so much energy poverty despite the rich energy resource available (Simonyan and Fasina, 2013; Vanguard Nigeria, 2013). But with the deployment of biogas from CRC, this serious health risk will be greatly alleviated. Secondly, the problem of water body pollution is prevalent in both urban and rural communities across Nigeria. Helmer et al., (1997) reported that natural water bodies such as streams and rivers still serve as drinking water source for many in rural areas, however, these water bodies are commonly polluted by organic substances from agricultural activities and upstream users. With an effective conversion of CRC to biogas, pollution of water bodies with this biomass will be greatly mitigated through the reduction in the release of these substances into landfills and water bodies. Thirdly, the digestate from the anaerobic digestion of this biomass could eventually be deployed as organic fertilizer/soil enhancement for crop production.

Bioenergy from CRC: From section 3.2, CRC has demonstrated a good biomethane potential to be a suitable feedstock (444.897 mL/gVS). The annual bioenergy derivable from cattle rumen content will vary depending on the amount of slaughtered cattle each year. The average derivable energy from CRC for the period under study is 1,522x10^6 Mega Joules per annum. A comparative examination of this potential with other renewable energy sources in Nigeria is presented in Figure 1. Though hydro power generation represents about 93% of renewable source, it however compares favourably with energy currently generated from others such as wind solar combined. Obiechefu et al. (2019) quantified potential power generation from selected agrowaste in Nigeria.

Table 5: Theoretical yield on biogas and biomethane for ten years in Nigeria

Year	TBY (m^3 CH_4/annum)	TMY (m^3 CH_4/annum)	Bioenergy production (10^6 MJ/annum)	Net energy capacity (gigawatt/annum)
2010	71,963,496.53	34,245,119.92	1,293.781	356.28
2011	82,656,503.11	39,333,578.79	1,486.023	359.38
2012	83,375,610.14	39,675,778.76	1,498.951	412.78
2013	84,100,981.10	40,020,959.53	1,511.992	416.38
2014	85,747,142.26	40,804,314.83	1,541.587	420.00
2015	87,620,307.14	41,695,693.92	1,575.263	428.22
2016	86,315,172.47	41,074,622.19	1,551.799	437.57
2017	87,066,111.41	41,431,969.95	1,565.300	431.06
2018	88,014,314.48	41,883,189.38	1,582.347	434.81
2019	89,700,932.95	42,685,797.01	1,612.669	439.54
Average/annum	84,656,057.16	40,285,102.43	1,521.971	447.96

They reported a potential of generating 1846 MW of electricity from agrowaste. The total renewable energy capacity in Nigeria from 2011 to 2019 in gigawatts is presented in Table 6 comparatively with the net energy from CRC. On average, the potential in adopting CRC as a means of generating renewable energy stands at about 448 gigawatt per annum which is over 200 times the current total renewable energy capacity in Nigeria.

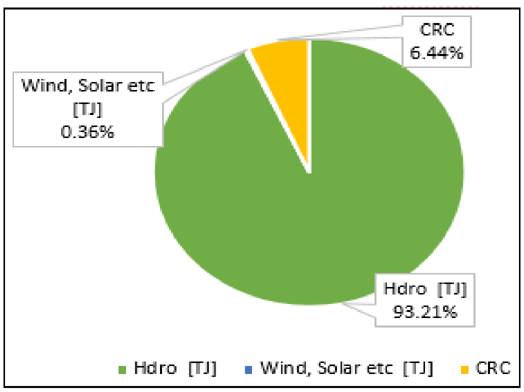

Fig 1: A representation of renewable energy sources in Nigeria

Table 6: Comparing the net bioenergy capacity from CRC and total renewable energy capacity in Nigeria

Year	Net energy capacity from CRC (gigawatt/annum)	Renewable Energy capacity (gigawatts/annum)**
2010	356.28	-
2011	359.38	2.12
2012	412.78	2.13
2013	416.38	2.14
2014	420.00	2.14
2015	428.22	2.14
2016	437.57	2.14
2017	431.06	2.14
2018	434.81	2.14
2019	439.54	2.15
Average/ annum	**447.96**	**2.14**

***Sourced from (Statista, 2022)*

Conclusion: This study has estimated the amount of energy in form of biomethane that can be potentially generated annually from cattle rumen content as feedstock in Nigeria through the AD process. When compared with the total renewable energy capacity in Nigeria, it potentially meets 200 times the current supply from other renewable energy sources. This exceeds energy currently being generated from wind, solar and other sources.

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