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Article

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Research paper

Potential for cleaner energy recovery and electricity generation from abattoir wastes in Nigeria



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ABSTRACT

Energy recovery and electricity generation from abattoir wastes was investigated with the aim of combating both energy crises and environmental pollution problems. Anaerobic digestion was carried out in a two 10 L batch digesters for about 30 days under mesophilic condition. Biogas volume was measured by water displacement method at every 24 h interval. Based on the volume of biogas produced and its methane composition, electricity value of the produced biogas was estimated. Daily average and cumulative gas volumes of 0.00103 m³/kg VS (1.03 liters) and 0.0309 m³/kg VS (30.90 liters) were obtained respectively with 63.4% methane composition. The results suggest that 1040 MWh and 1664.6 MWh of electricity can be generated from biogas at low-end conversion efficiency of 25% and at high-end conversion efficiency respectively. The study concluded that waste to wealth technology, if appropriately explored is a viable solution to energy crises in Nigeria.

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1. Introduction

Energy crisis in Nigeria has drawn attention to the need for search for alternative sources of energy to complement or possibly replace the underground fossil fuel. Energy demand in Nigeria has greatly increased due to the growing rate of industrialization, population and development. In recent time, the generation, transmission and distribution of energy in Nigeria have continued to grow from bad to worse. Availability of constant energy supply for agricultural, domestic and industrial purposes is one of the indices of infrastructural development in any civilized community. Consumption of energy is a reflection of the level of development of any nation because it contributes immensely to the socio-economic growth of the nation (Kanagawa and Nakata, 2007; Sokona et al., 2012; Akhator et al., 2016). Major obstacle to Nigeria's economic growth has been traced to poor access to electricity (Adeyemi, 2013). In recent years, electricity consumption in Nigeria has been on continuous increase (Fig. 1) and this is consequential of the low level of development as well as socio-economic challenge being faced by the nation (Global Economy Indicator). Moreover, over-dependence on fossil fuel as the major source of energy has been reported to be one of the causes of global climate change, environmental degradation and other

pollution problems (Sunarso et al., 2012). Apart from possible depletion of oil in the nearest future, in Nigeria, the incessant rise in the pump price has brought untold hardship for man's reliance on oil for both domestic and commercial energy requirements.

In many rural areas of Nigeria, access to fossil fuel and petroleum products poses a serious challenge due to the high cost involved. As a result of these problems, there is an urgent need to search for new alternative energy source – especially renewable energy source. Renewable energy technologies effectively use natural resources which may be replenished and these include solar power, wind power, hydroelectricity, biomass and biofuel (Rabah et al., 2010).

Recently also, increase in meat production for the increasing Nigerian population has resulted in upsurge in the number of abattoir or slaughter-houses springing up in major cities in Nigeria (Abiade-Paul et al., 2006). The activities of these abattoirs are unregulated by government agencies, hence there is no adherence to sound waste disposal management system. During abattoir operation, numerous wastes are generated which do not only constitute a menace to effective environmental management but also are associated with reduction in air quality of the environment, potential transferable antimicrobial resistance patterns, and many infectious organisms which can be pathogenic to human (Abiade-Paul et al., 2006). It has been reported that Nigeria produces about 227,500 tons of fresh animal wastes on daily basis (Oyeleye et al., 2003; Mshandete and Parawira, 2009) with 1 kg of these fresh wastes capable of producing 0.03 m³ of gas per

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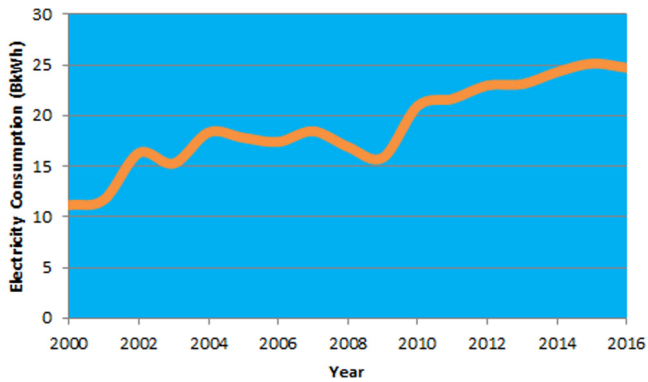


Fig. 1. Energy consumption trend in Nigeria (2002–2016).
Source: Computed from Global Economy Indicator Database.

day (Rabah et al., 2010). According to Aniebo et al. (2009), typical abattoir that slaughters about ten cows daily generates 3880 kg of solid wastes on daily basis. Several other studies have equally reported large quantum of wastes generated from abattoir facility in Nigeria on daily basis and the adverse effect of this on public health (Nwanta et al., 2008; Omole and Ogbiye, 2013; Fearon et al., 2014; Oruonye, 2015; Onuoha et al., 2016; Umunnakwe and Njoku, 2017). It is therefore, of necessity to search for the utilization of the waste to generate biogas through anaerobic digestion, the approach will provide alternative energy source. Biogas has methane content in the range of 60–68.53%, which makes it a veritable fuel/energy source (Alfa et al., 2013; Odejobi et al., 2016; Dahunsi et al., 2017a,b, 2019a,b,c,d). Study by Jekayinfa et al. (2015) documented biogas volume range of 0.42–0.56 m³ daily from selected crop residues. Dahunsi et al. (2017a,b) established biogas generation from fruit peels of *carica papaya* and reported cumulative biogas volume 0.1839 m³ in 30 days. Similarly, lemon grass was co-digested with cow dung by Alfa et al. (2013) for 30 days in a 25-liter pilot scale anaerobic digester and the study reported a total of 0.146 m³ of biogas. Several other researchers have investigated anaerobic digestion under mesophilic condition for biogas production from variety of wastes (Ogbeide and Aisien, 2000; Anozie et al., 2005; Dahunsi et al., 2016). Large quantities of abattoir wastes being produced by slaughterhouses daily with their accompanying pollution problems, energy crises in developing countries as well as dearth of reported information on the use of abattoir waste for biogas production triggered this study. Production of biogas from abattoir wastes will be a panacea to the waste disposal problems as well as partial remedy to energy crises in Nigeria.

The focus of this study is therefore to assess the viability of abattoir wastes for energy recovery and electricity generation; which could complement the supply from National grid. In this study, electricity value was estimated from the volume of biogas produced and its methane content as well as the average number of cows slaughtered in Nigeria daily.

2. Material and methods

2.1. The abattoir waste

Abattoir waste used in this study was a mix of cow dung and wastewater and these were collected from a slaughterhouse in Ile-Ife, South West Nigeria. Slurry of the waste was obtained by mixing this with distilled water in the ratio 3:1:2. Fresh rumen content of adequate microbial flora needed for anaerobic digestion to take place was also added to the slurry to act as inoculum. The pH, total solid (TS), volatile solid and soluble oxygen

demand (SCOD) concentration in the wastewater were 6.5 ± 0.1 , 660.2 ± 4 mg TS/l, 534.7 ± 2.1 mg VS/l and 688.5 ± 3.2 mg COD/l; in the cow dung were 6.4 ± 0.1 ; 632.7 ± 2.4 mg TS/kg, 575 ± 2.0 mg VS/kg and 1230 ± 88 mg COD/l and in the rumen content were 6.82 ± 0.11 , 9.08 ± 0.12 mg TS/kg and 9.20 ± 2.1 mg VS/kg and 160.20 ± 1.12 mg COD/l respectively.

2.2. Characterization of the substrate

2.2.1. Characteristics of abattoir waste

It has been established that, prior to anaerobic digestion, substrate must be adequately characterized (Dahunsi et al., 2018). With this fact in mind, slurry of the waste was characterized in order to quantify their important properties. The characterization was carried out before and at the end of anaerobic digestion at Hydrobiology laboratory of Obafemi Awolowo University, Ile Ife according to standard methods (APHA, 2012). For the determination of Chemical Oxygen Demand (COD), the American Public Health Association, (2012) standard methods for the examination of water and wastewater subsequently used by Ayandiran and Dahunsi (2016) were employed. Total solids (TS) and volatile solids (VS) were determined using the SFS 3008 protocol of the Finnish Standard Association (1990). To evaluate the performance of the digester, daily analysis of the digesting substrate for COD, TVS, pH and TS and temperature were carried out according to standard procedure (Association of Official Analytical Chemists, AOAC, 2000). pH and temperature were measured using hand-held pH meter and thermometer respectively. Proximate analysis (determination of moisture, ash, crude fiber, crude nitrogen and crude protein contents, etc.) was carried out before and after digestion at Animal Science laboratory, Obafemi Awolowo University, Ile- Ife, according to standard procedure as described by AOAC (2000) and subsequently employed by Nwosu et al. (2011).

2.3. The digester and experimental procedure

Automated anaerobic digesters (Edibon PDANC 0007/144) with attachment of two 10 L reactors each were used for this study. The reactors were air-tight with loading opening, sample withdrawal outlet and an automated agitation mechanism. Water tank and water collector were attached to the back of the digester. The slurry of the waste (henceforth referred to as substrate) was loaded into the digester to occupy about 75% of the total digester volume leaving a clear space for the gas build-up. Using a batch digestion process, the digester was operated for 30 days under mesophilic condition. The volume of biogas generated from the process is measured every 24-hour interval by waster displacement method. Chromatographic analysis of the biogas produced was done using gas chromatography 5890 series II model with thermal conductivity detector (TCD). The column used was Haysep Q (80/100 mesh) with a length of 10 ft. × 1/8 in. having detector temperature of 150 °C while helium gas with 25 psi was used as a carrier gas (mobile phase).

2.4. Determination of cooking potential of the biogas produced

The cooking potential of biogas produced from abattoir wastes was evaluated using boiling test as described by Odejobi et al. (2016). The biogas produced was ignited to boil water and rice separately using a specially designed burner. The time taken for the boiling, which corresponds to the calorific value of the biogas was recorded (Alfa et al., 2013; Odejobi et al., 2016; Dahunsi et al., 2019a,b,c,d).

Table 1
Proximate analysis before and after anaerobic digestion.

Parameter	Pre- digestion	Post digestion
Moisture content (%)	75.23	85.24
Ash content (%)	5.64	12.31
Crude fiber (%)	2.36	1.40
Crude protein (%)	14.42	9.87
Total nitrogen (%)	2.31	1.58
Total carbon (%)	52.42	54.27
C: N	22.69	34.34

2.5. Estimation of electricity potential of the biogas produced from abattoir wastes

Based on the daily average number of cows consumed/ slaughtered in Nigeria, the daily average biogas produced and its methane composition, the energy from the biogas which can be converted to electricity was calculated (see Appendix A) using Eq. (1) and appropriate conversion efficiency as documented in literatures (Jekayinfa et al., 2015)

$$e_{\text{biogas}} = E_{\text{biogas}} \times \eta \quad (1)$$

where, E_{biogas} represents the unconverted raw energy in the biogas, e_{biogas} is the total electricity that can be generated from biogas and η is the overall conversion efficiency.

3. Results and discussion

3.1. Characterization and biogas generation

Proximate analysis results before and after anaerobic digestion periods are presented in Table 1. Post anaerobic digestion moisture content of the sample was higher than moisture content in the pre-digestion sample and this was responsible for the reverse case of the ash content. Total carbon also continued to increase till after the digestion period and this suggests a continuous increase in the energy source available for active and suitable microbial environment for increased biodegradability of the substrate. However, continuous utilization of nitrogen for protein requirement led to decline in the available total nitrogen for microbial activities. This is manifested in the increase in C: N ratio from 22.69 to 34.34. Based on previous studies, the C: N ratio in this study is not only considered suitable for biogas generation but also, among other factors, high C: N ratio above 30 could contribute to the stoppage of biogas generation because of deficiency in nitrogen for microbial activities (Romano and Zhang, 2008; Uzodinma and Ofoefule, 2009; Dahunsi, 2019a,b). Also higher concentrations of volatile fatty acids (acetic, propionic and butyric acids) were recorded at the beginning of the digestion than at the end. Acetic acid was most prominent with highest concentration (Fig. 2) possibly because of higher activities of acidogens than methanogens. As biogas generation commenced, consumption of acetate resulted into conversion of acetic acid to methane and CO_2 , hence decrease in total volatile fatty acids (TVFAs) after the digestion (from 4.65 mg/l to 2.10 mg/l). This observation is in consonance with similar previous studies (Montero et al., 2008; Ajay et al., 2012).

Biogas generation commenced on the sixth day and progressed until fifteenth day after which a fall was observed and remained diminishing till the end of the experiment as presented on Table 2. The first five day period is thought to correspond to the hydrolysis and acid formation period of the substrates. It may also be due to the presence of lignin and wax in the undigested rumen content in the substrate which decreases the rate of digestion (Anozie et al., 2005). Apart from this, in the first two days, the pH value declined from 6.4 to 6.3. This is thought to be due to

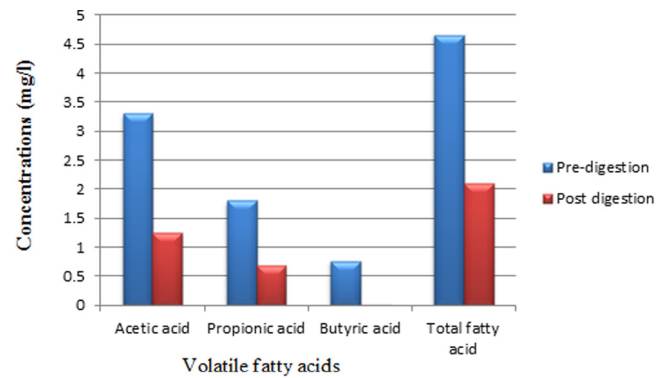


Fig. 2. Concentrations of volatile fatty acids before and after digestion periods.

the fact that methanogenic bacteria are not favored at hydrolytic stage of anaerobic digestion process (Zhang et al., 2013). At this stage, methanogenic organisms are unable to catabolize the organic acid being produced by hydrolytic bacteria. This results in the accumulation of acid in the reactor and thus makes the pH value to be slightly acidic. However, as the methanogenic bacteria increased in population, the ability of acid metabolism became strong and the pH gradually increased until it remained buffered around 7.1 when gas production started in the reactor (day 6). This continued as the substrate showed a general increase in pH with minimal fluctuation. The daily gas generation therefore increased steadily and reached on the fifteenth day with peak volume of 0.0025 m^3 kg VS at a pH of 7.5 and Chemical oxygen demand COD, total solid TS and total volatile solid TVS of 350.24 mg/l, 431.81 and 258.14 mg/l respectively. This is attributed to exponential growth of methanogenic bacteria. After this period (day 18th), the daily biogas yield began to decline as the growth of the methanogens reduced. This trend is predicted because the rate of biogas production in a batch condition is directly proportional to the specific growth of methanogenic bacteria (Maria et al., 2014; Rajasekaran and Manikandan, 2015). Daily average and cumulative gas volumes of 0.00103 m^3 /kg VS (1.03 liters) and 0.0309 m^3 /kg VS (30.90 liters) were obtained respectively. Trends observed in the production of biogas in this study are in agreement with previous studies in which daily biogas yield increased steadily for some days after which decrease in the volume of the gas continued until the end of the digestion (Anozie and Adebayo, 2009; Chinenyenwa et al., 2014; Dahunsi et al., 2016, 2017a,b). Different substrates have also been reported to have different periods when peak biogas production will be reached (Odeyemi and Adewumi, 1982) due to difference in the biodegradability of the substrates. Biogas yield in this study is lower than what was reported by Ogbeide and Aisien (2000) but comparable to the yield reported by Chen et al. (2008). The percentage composition of methane in the obtained from the chromatographic analysis of the biogas produced was 63.4%. Range of biogas methane contents of 60.3–68.53% have been documented by previous researchers, depending on the biodegradable wastes being utilized (Alfa et al., 2013; Odejobi et al., 2016; Dahunsi et al., 2017a,b, 2019a,b,c,d) and thus comparable with the results of this study.

3.2. Cooking potential of the biogas produced

As shown in Table 3, in the first run of evaluation, 0.0055 m^3 of biogas boiled the water and rice at 0.05 l/min and 0.0055 kg/min respectively. Similarly in the second run, 0.0056 m^3 of the biogas boiled the water and the rice at 0.05 l/min and 0.0048 kg/min respectively. In the third run, 0.05 liter of water and 0.0052 kg of rice were boiled in one minute by 0.0055 m^3 of biogas whereas,

Table 2

Daily and cumulative biogas yields at different temperatures and pH of the substrate with daily COD, TS and TVS.

Retention time (days)	pH	Temp (°C)	COD (mg/l)	TS (mg/l)	TVS (mg/l)	Daily biogas yield (m ³)	Cumulative biogas yield (m ³)
1	6.4	29	1905.45	754.20	604.01	–	–
2	6.3	30	1734.31	738.19	590.23	–	–
3	6.5	30	1610.20	711.07	561.10	–	–
4	6.8	30	1589.78	697.83	532.45	–	–
5	7.0	30	1509.22	679.12	501.11	–	–
6	7.1	31	1472.18	655.10	482.89	0.0003	0.0003
7	7.1	30	1419.05	631.23	463.48	0.0005	0.0008
8	7.2	30	1364.11	609.17	432.17	0.0005	0.0013
9	7.2	30	1215.00	582.00	411.32	0.0007	0.0020
10	7.2	31	1113.14	573.41	402.14	0.0010	0.0030
11	7.2	32	1091.24	561.33	387.37	0.0010	0.0040
12	7.3	30	1011.73	545.18	369.07	0.0020	0.0060
13	7.3	30	963.14	537.29	355.20	0.0020	0.0080
14	7.4	32	904.73	517.08	349.15	0.0020	0.0100
15	7.5	31	809.27	488.26	320.63	0.0025	0.0125
16	7.3	32	792.04	474.92	309.01	0.0024	0.0149
17	7.4	30	763.11	454.10	295.14	0.0025	0.0174
18	7.3	31	743.16	435.09	281.72	0.0025	0.0199
19	7.4	31	643.57	420.23	272.03	0.0020	0.0219
20	7.5	31	600.65	380.54	263.19	0.0020	0.0239
21	7.5	33	561.03	365.08	250.56	0.0020	0.0259
22	7.5	32	521.29	351.52	240.31	0.0018	0.0277
23	7.5	30	480.64	325.39	221.32	0.0015	0.0292
24	7.5	30	442.14	310.03	210.43	0.0010	0.0302
25	7.5	30	412.11	290.10	195.16	0.0005	0.0307
26	7.5	30	401.72	273.45	176.04	0.0002	0.0309
27	7.6	28	381.42	255.73	161.39	0	0.0309
28	7.5	30	362.30	231.38	145.27	0	0.0309
29	7.5	30	332.47	200.32	120.07	0	0.0309
30	7.5	30	302.19	173.91	102.53	0	0.0309

Table 3

Determination of cooking potential of the gas produced.

Run	Volume of water (L)	Quantity of rice (kg)	Volume of gas consumed (m ³)	Time taken (s)
1	0.05	0.0050	0.0055	61
2	0.05	0.0048	0.0056	60
3	0.05	0.0052	0.0055	60
4	0.05	0.0049	0.0055	61
5	0.05	0.0053	0.0056	60
Average	0.05	0.0050	0.0054	60

0.05 liter of water and 0.0049 kg of rice were boiled in one minute by 0.0055 m³ of biogas in the fourth run. In the last run, 0.0056 m³ of biogas boiled the water and rice at 0.05 l/min and 0.0055 kg/min respectively. This showed that at the consumption rate of 0.00504 m³/min; the water and the rice boiled at the average rates of 0.05 l/min and 0.005 kg/min respectively. Results from similar previous studies on combustibility of biogas were comparable to the result obtained in this study. For the same commodities for instance, Alfa et al. (2013) reported cooking rates of biogas from the mixture of cow dung and lemon grass to be 0.07 l/min and 0.0034 kg/min respectively with the consumption rate of 0.0049 m³/min, while biogas from co-digestion of cocoa pod and poultry manure as reported by Dahunsi et al. (2019a,b,c,d) had cooking rates of 0.16 l/min and 0.0049 m³/min respectively, with consumption rate of 0.0057 m³/min. The slight variation could be attributed to the difference in the wastes used. This is an indication that the biogas produced in this study achieved its targeted usage as a cooking fuel.

3.3. Energy and electricity value of biogas produced

The energy from biogas can be converted to electricity with a typical conversion efficiency of 34%–40%, for large turbine) and 25% for small generators (Tafdrup, 1995; Nielsen et al., 2007; Murphy et al., 2004; Cuéllar and Webber, 2008; Lansing et al.,

2008; Jekayinfa et al., 2015). The estimation (see Appendix A) is based on the average number of cows consumed/slaughtered in Nigeria daily. Based on 25% conversion efficiency (low-end conversion), the estimated total electricity that can be generated from biogas was found to be 2,850.4 kWh while based on 40% conversion efficiency (high end conversion), it was found to be 4560.70 kWh. This implies that, 2,850.4 kWh and 4560.70 kWh of electricity can be generated daily from biogas produced from cow wastes at a low-end efficiency of 25% and at the high-end conversion efficiency of 40% respectively which on annual basis, yields 1040 MWh and 1665 MWh respectively.

Going by the reports of Oyeleye et al. (2003) and Anthony and Wilson (2008) which documented that about 227,500 tonnes of fresh animal wastes are generated daily in Nigeria, the potential for generation of electricity from biogas (using animal wastes) is enormous. Previous research have also predicted that about 24.08 million and 38.52 million kWh of electricity can be generated from biogas at a low-end efficiency of 25% and at the high-end conversion efficiency of 40% respectively using only seven crop residues in Nigeria (Jekayinfa et al., 2015). These higher values are thought to be connected to the use of several wastes as against the use of only one waste in this study. It is therefore clear, that the more the amount of biodegradable wastes used in the anaerobic digestion process, the more the methane content and the more the amount of electricity being produced. With the observed large quantum of abattoir and other degradable wastes being generated on daily basis and adequate waste-to-energy plants put in place; higher biogas production which will in turn result in greater amount of electricity could be generated. Depending on the conversion technology being utilized, this can be injected to national or regional grid and thus contribute to annual electricity generation to alleviate some of the challenges being faced by Nigerians due to non-availability of electricity supply.

4. Conclusion

Some of the major issues facing Nigeria are poor access to energy and waste disposal problems. Interestingly, these challenges can be converted to gain which could immensely improve the socio-economic growth of Nigeria. The study investigated the viability of energy recovery and electricity generation from abattoir waste with a view to provide solution to both waste disposal problem as well as energy crises. The result indicated that the biogas produced has high methane content of about 63.4% which could be converted to energy. Based on this methane composition, 1040 MWh and 1665 MWh was generated from biogas at low-end conversion efficiency of 25% and at high-end conversion efficiency respectively utilizing only abattoir wastes. It implies that the abundance of agricultural and municipal wastes could be made to provide solution to current poor supply of energy in Nigeria. The study therefore concluded that waste-to-wealth technology, if appropriately explored is a viable remedy to energy crises in Nigeria

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

The estimation of electricity production from biogas produced from abattoir waste is as follows:

Daily average number of cows consumed in Nigeria = 90,000 (Sunnewsonline, 2017)

Daily average waste generated per cow = 38.8 kg (Aniebo et al., 2009; Chukwu et al., 2011)

Daily waste generated by cows in Nigeria = $(38.8 \times 90,000)$ kg = 3,492,000 kg

Mixing 3 492 000 kg of waste with water in the ratio 2:1 forms slurry of 10,476,000 kg = 10 476 tons

By simple proportion, 6 kg of abattoir waste slurry from this study (that is cow dung, abattoir waste water and distilled water in ratio 3:2:1) produced daily average of 0.00103 m³ of biogas, under the same conditions; 10,476,000 kg is expected to produce daily average of 1798.38 m³ of biogas

This implies that Nigeria has potential to produce daily average of 1798.38 m³ from cow alone

Calorific value of pure (100%) methane = 10 kWh/m³ (SGC, 2012)

Calorific value of the biogas based on methane content of 63.4%

$$= 10 \text{ kWh/m}^3 \times 0.634$$

$$6.34 \text{ kWh/m}^3$$

Total energy generated (kWh) per day based on 63.4% methane content = $1798.38 \text{ m}^3 \times 6.34 \text{ kWh/m}^3 = 11,401.73 \text{ kWh}$.

Energy value of biogas produced = 11,401.73 kWh

This implies that daily average of about 11,401.73 kWh energy can be generated from cow waste alone in Nigeria.

This can be converted to electricity using
Using Eq. (1) proposed by Jekayinfa et al. (2015),

$$e_{\text{biogas}} = E_{\text{biogas}} \times \eta$$

where, E_{biogas} represents the unconverted raw energy in the biogas, e_{biogas} is the total electricity that can be generated from biogas and η is the overall conversion efficiency. For this analysis the range of efficiencies used was 25%–40%.

At low-end conversion (when $\eta = 0.25$): $e_{\text{biogas}} = (0.25 \times 11\,401.73) \text{ kWh} = 2850.4 \text{ kWh}$

At high-end conversion (when $\eta = 0.40$): $e_{\text{biogas}} = (0.40 \times 11\,401.73) \text{ kWh} = 4560.70 \text{ kWh}$

Annual generation:

At low-end: $2850.4 \text{ kWh} \times 365 = 1\,040\,407.86 \text{ kWh}$
= 1040 MWh

At high-end : $4560.70 \text{ kWh} \times 365 = 1,664,652.58 \text{ kWh}$
= 1665 MWh.

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