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Research Article

Comparative Assessment of Biogas Accumulation and Theoretical Electrical Energy Potential from Animal Wastes under Ambient Conditions

*Y.D. Musa[1a], A. Lawan[1b], A. I. Muhammad[2c], Zainab Abubakar[2d], Raihana Yakubu[2e], Y. M. Shingu[2f]

[1] Department of Physics, Faculty of Physical Sciences, Modibbo Adama University, P.M.B. 2076, Yola, Adamawa State, Nigeria.
[2] Department of Science and Laboratory Technology, Adamawa State Polytechnic, P.M.B. 2146, Yola, Adamawa State, Nigeria.
[a] **ORCID:** 0009-0004-6767-5771 | [b] **ORCID:** 0009-0001-6181-9138 | [c] **ORCID:** 0009-0008-2376-662X

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***Corresponding Author: Y.D. Musa**
Department of Physics, Faculty of Physical Sciences, Modibbo Adama University, P.M.B. 2076, Yola, Adamawa State, Nigeria.
ORCID: 0009-0004-6767-5771 | **E-mail:** ydmusa@mau.edu.ng

Abstract

The utilization of animal wastes for biogas production offers opportunities for renewable energy recovery and improved waste management. This study comparatively assessed short-term biogas accumulation and theoretical electrical-energy potential from cow dung, goat dung and poultry droppings under ambient anaerobic digestion conditions. Three airtight 10-L batch digesters were separately loaded with 2kg of animal waste and 5kg of water without external inoculation. Following an initial 48-hour fermentation period, gas accumulation was monitored for ten days using rigid, airtight 1-L collectors connected through valved tubing. Eight balance readings were obtained daily, while ambient temperature was monitored. Theoretical electrical-energy potential was estimated using an assumed methane mole fraction of 0.60, methane lower heating value of 50MJ kg^{-1} and electrical conversion efficiency of 25%. Ambient temperature ranged from 32.34 to 33.53°C, while initial slurry pH varied between 6.40 and 6.80. On day 10, poultry droppings recorded the highest mean cumulative mass reading of 0.01140kg, followed by cow dung (0.00741kg) and goat dung (0.00480kg). The corresponding conditional theoretical electrical-energy estimates were 50.37, 32.74 and 21.21kJ, respectively. The novelty lies in integrating short-term gas-accumulation observations with a theoretical electrical-energy assessment under common ambient digestion conditions. The results provide a basis for further investigation of animal-waste utilization in small-scale biogas-to-electricity systems.

Keywords: *Anaerobic digestion; Animal wastes; Biogas accumulation; Electrical-energy potential; Renewable energy; Waste-to-energy.*

1. Introduction

The increasing demand for energy, depletion of conventional fossil fuel resources, and environmental concerns associated with greenhouse gas emissions have intensified research into renewable energy technologies. Among the available alternatives, biomass-derived energy has received considerable attention because of its potential to convert biodegradable organic materials into useful energy products. Agricultural residues, livestock wastes, and other organic materials can be utilized for energy recovery through anaerobic digestion, thereby combining renewable energy production with improved waste management [1],[2],[3]. Biogas production is particularly relevant to agricultural communities where organic wastes are readily available and decentralized energy systems could supplement conventional energy supplies.

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Anaerobic digestion involves the decomposition of organic matter by microorganisms under oxygen-free conditions through hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The resulting biogas consists primarily of methane (CH_4) and carbon dioxide (CO_2), together with smaller quantities of other gaseous constituents. Methane is the principal combustible component and determines much of the energy content of biogas. The quantity and composition of gas produced depend on the characteristics of the substrate and operating parameters, including temperature, pH, microbial activity, substrate concentration, and digestion time [4],[5],[6]. Animal wastes are suitable substrates because they contain biodegradable organic matter and naturally occurring microbial populations. Nevertheless, cow dung, goat dung, and poultry droppings differ in their organic composition, moisture content, nutrient availability, and biodegradability, which may influence their gas-accumulation characteristics under comparable operating conditions. In particular, nitrogen-rich substrates such as poultry droppings may experience ammonia inhibition when the concentration of available nitrogen becomes excessive [7],[8].

Several studies have investigated biogas production from animal wastes under different experimental conditions. Olowoyeye [9] compared six animal wastes and reported that chicken dung produced more biogas than cow dung and goat dung. Alfa et al. [10] investigated poultry droppings, cow dung, and lemon grass over a 30-day digestion period and obtained higher cumulative biogas production from poultry droppings than from cow dung. More recently, Ugwuoke et al. [11] examined cow dung, goat droppings, and chicken droppings, both individually and in combination, using laboratory-scale digesters over 30 days. Their findings showed that chicken droppings produced the highest cumulative gas volume among the individually digested substrates. These studies demonstrate the influence of substrate characteristics on biogas production. However, differences in digester configuration, substrate loading, measurement procedures, and digestion duration limit direct numerical comparisons among the reported results.

The operating conditions of anaerobic digesters also influence gas-production characteristics. Karim et al. [12] investigated the effects of mixing on anaerobic digestion of animal wastes, while Koyuncu and Nas [13] examined relationships among volatile acids, alkalinity, retention conditions, and biogas production. Angelidaki et al. [6] emphasized the importance of standardized experimental procedures for evaluating biochemical methane potential. Although temperature-controlled digestion systems provide opportunities for regulating microbial activity, small-scale digesters may operate under ambient environmental conditions without external heating. Investigating short-term gas accumulation under such conditions can provide preliminary information relevant to simple anaerobic digestion systems, particularly where operational resources are limited.

Beyond the production of combustible gas, the possibility of converting biogas into electricity provides an additional motivation for animal-waste utilization. The electrical energy obtainable from biogas depends principally on the quantity of methane available, its heating value, and the electrical conversion efficiency of the generating system. Uddin et al. [14] reviewed the potential of biogas for electric-power generation, while Ertop et al. [15] assessed biogas and electricity-production potential from cattle waste. These investigations establish the relevance of biogas to renewable electricity supply. However, reliable electrical-energy estimation requires appropriate characterization of the gas and specification of the energy-conversion assumptions. Where methane concentration, standardized gas volume, and generator efficiency are not experimentally determined, theoretical estimates must be distinguished from actual electricity generation.

Despite the availability of comparative studies on animal-waste digestion, the published investigations discussed above do not establish the short-term accumulation characteristics of the three selected wastes under the specific loading, ambient operating, and gas-collection conditions employed in the present experiment. Furthermore, the connection between the recorded short-term accumulation measurements and conditional theoretical electrical-energy estimates requires explicit consideration of measurement uncertainty and assumed conversion parameters. This constitutes the specific research gap addressed by the present investigation, rather than an absence of earlier comparisons of cow dung, goat dung, and poultry droppings.

The distinctive contribution of this study is the combined assessment of short-term gas accumulation and theoretical electrical-energy potential from the three animal wastes using a common experimental configuration. Unlike the longer-duration, volume-based investigations reported in [9],[10],[11], the present work considers ten-day accumulation patterns obtained from separate 10-L batch digesters, each loaded with 2 kg of animal waste and 5 kg of water, without an external inoculum. The digesters were operated under ambient laboratory conditions, and gas accumulation was examined through repeated mass readings from rigid, airtight collectors. The recorded measurements are subsequently considered within a theoretical electrical-energy framework based on specified methane-composition and conversion-efficiency assumptions. This combination provides a preliminary basis for comparing the selected wastes while explicitly distinguishing experimental observations from conditional energy estimates. Since collector pressure and methane concentration were not measured, the analysis does not claim verified biogas mass yields or experimentally demonstrated electricity generation.

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The objective of the present study is to compare the short-term gas-accumulation readings obtained from cow dung, goat dung, and poultry droppings under ambient anaerobic digestion conditions and to assess their theoretical electrical-energy potential. Particular attention is given to the variation of recorded accumulation with digestion time, differences among the three substrates, and the corresponding energy estimates under stated assumptions. The results are intended to provide preliminary information on animal-waste utilization and identify the measurement requirements for more reliable assessments of small-scale biogas-to-electricity systems.

2. Theoretical Framework

This section presents the theoretical principles and mathematical formulations governing biogas accumulation and its potential conversion into electrical energy. The framework establishes the relationships among accumulated gas mass, digestion time, temperature, pressure, and gas composition. The chemical energy associated with methane content is subsequently related to theoretical electrical-energy potential through an assumed conversion efficiency. The resulting equations provide the basis for interpreting the experimental observations, comparing the selected animal wastes, and evaluating their theoretical electrical-energy potential under specified assumptions and measurement limitations.

2.1. Mathematical Description of Biogas Accumulation

Biogas accumulation during anaerobic digestion results from the microbial decomposition of biodegradable organic matter under oxygen-free conditions. The quantity of gas produced depends on the characteristics of the substrate, microbial activity, digestion temperature, and fermentation duration [4],[6],[12]. In a batch digestion system, biogas is progressively generated and transferred into a collection vessel, where its accumulated quantity can be monitored over time. The mathematical description of this process provides a basis for examining temporal variation in gas accumulation and comparing different animal wastes under similar conditions.

The cumulative mass of biogas transferred into a collector over a digestion period t can be expressed as

$$m_b(t) = \int_0^t \dot{m}_b(\tau)\, \mathrm{d}\tau \qquad (1)$$

Here, $m_b(t)$ is the cumulative biogas mass (kg), $\dot{m}_b(\tau)$ is the instantaneous mass-flow rate (kg per second), and τ is the integration variable. Equation (1) assumes that gas transferred into the collector is retained without leakage or reverse flow. For discrete collection intervals, the corresponding relationship is

$$m_{b,i} = m_{b,i-1} + \Delta m_{b,i} \qquad (2)$$

In Eq. (2), $m_{b,i}$ and $m_{b,i-1}$ denote cumulative masses at successive observations, whereas $\Delta m_{b,i}$ is the mass admitted during observation interval i.

In the present experiment, rigid, airtight gas collectors were supported continuously by digital balances. The apparent increase relative to the initial balance reading is

$$m_{\mathrm{app},i} = M_i - M_0 \qquad (3)$$

Here, $m_{\mathrm{app},i}$ is the apparent accumulated mass (kg), M_i is the balance reading at observation i, and M_0 is the initial reading before gas collection. Because the collectors remained connected to the digesters through tubing, the apparent mass change cannot automatically be equated with gas mass: forces transmitted by the tubing and instrumental uncertainty may contribute to the reading.

The mean apparent cumulative reading for digestion day d is given by

$$\overline{m}_{\mathrm{app},d} = \frac{1}{N}\sum_{i=1}^{N} m_{\mathrm{app},d,i} \qquad (4)$$

In Eq. (4), $\overline{m}_{\mathrm{app},d}$ denotes the daily mean apparent cumulative mass, N is the number of readings per day, and $m_{\mathrm{app},d,i}$ is the apparent cumulative mass at reading i on day d. In this study $N = 8$, corresponding to observations between 10:00 and 17:00. Because gas was retained in the collectors, these daily means must not be added to obtain total production.

For two feedstocks A and B, the relative difference in recorded mean cumulative accumulation on the same day is

$$D_{AB} = \frac{\overline{m}_{\mathrm{app},A} - \overline{m}_{\mathrm{app},B}}{\overline{m}_{\mathrm{app},B}} \times 100\% \qquad (5)$$

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Here, D_{AB} is the percentage difference relative to feedstock B; the two mean readings must refer to the same digestion day. This descriptive comparison does not imply statistical significance because only one digester was used for each feedstock. Equations (1)–(5) provide the basis for describing gas accumulation while retaining the distinction between balance-derived readings and independently verified biogas mass.

2.2. Thermodynamic Description of Biogas

The thermodynamic behaviour of biogas in a closed collection system is governed by the relationships among pressure, volume, temperature, gas mass and molecular composition. Since the present experiment employed rigid, airtight collectors, these relationships are important for interpreting the recorded gas accumulation and establishing the basis for subsequent electrical-energy calculations. The ideal gas model provides a first approximation, provided the gas mixture behaves approximately ideally and the relevant thermodynamic conditions are specified [4],[6].

For a gas mixture, the equation of state is

$$PV = nRT \tag{6}$$

where P is absolute pressure (Pa), V is gas volume (m^3), n is the amount of gas (mol), R = 8.314462618 $Jmol^{-1}$ K^{-1} is the universal gas constant, and T is absolute temperature (K).

The amount of gas can be expressed in terms of its mass and mean molar mass as

$$n = \frac{m_b}{\overline{M}} \tag{7}$$

where m_b is gas mass (kg), and $\bar{M}$ is mean molar mass (kg mol^{-1}).

For a simplified mixture containing methane and carbon dioxide, the mean molar mass is

$$\overline{M} = x_{CH_4} M_{CH_4} + \left(1 - x_{CH_4}\right) M_{CO_2} \tag{8}$$

where x_CH_4 is methane mole fraction, and M_CH_4 and M_CO_2 are the molar masses of methane and carbon dioxide, respectively. This two-component composition is an assumption, not a measured property of the collected gas.

Combining Eqs. (6) and (7), gas mass is related to pressure, volume, and temperature through

$$m_b = \frac{PV\overline{M}}{RT} \tag{9}$$

For a rigid collector at approximately constant temperature and volume, the additional gas mass and the corresponding increase in absolute pressure are related by

$$\Delta P = \frac{\Delta m_b RT}{\overline{M}V} \tag{10}$$

Equation (10) assumes a known mean molar mass of the introduced gas and constant temperature and collector volume. It indicates that admitting gas into a rigid container increases internal pressure. If the collector initially contained air, that initial gas must also be considered when interpreting total pressure.

The gas volume corresponding to a known gas mass at selected reference conditions is

$$V_{ref} = \frac{m_b RT_{ref}}{\overline{M}P_{ref}} \tag{11}$$

where V_{ref}, T_{ref}, and P_{ref} denote reference volume, absolute temperature, and absolute pressure, respectively. The reference conditions must be stated when reporting a standardized gas volume.

Equations (6)–(11) establish the thermodynamic relationships relevant to rigid gas collectors. In the present investigation, internal collector pressure and methane concentration were not measured. Moreover, apparent balance changes could have been influenced by mechanical forces associated with the connected tubing. Consequently, actual gas mass and standardized gas volume cannot be independently verified from the available measurements. The equations are therefore used to define the assumptions and constraints of subsequent theoretical energy estimates, not to validate the recorded masses.

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2.3. Theoretical Chemical Energy of Biogas

The chemical energy available from biogas originates mainly from methane, whereas carbon dioxide contributes no appreciable heating value. Consequently, the quantity of biogas alone does not determine its fuel-energy content: methane composition and the relevant lower or higher heating value must also be specified. For a comparison directed towards electrical-energy conversion, the lower heating value (LHV) provides a consistent basis because it excludes the latent heat of condensation of water formed during combustion [4],[14].

For an idealized biogas mixture containing methane and carbon dioxide, the methane mole fraction is defined by

$$x_{CH_4} = \frac{n_{CH_4}}{n_b} \tag{12}$$

where X_{CH_4} is the methane mole fraction, n_{CH_4} is the amount of methane (mol), and n_b is the total amount of biogas (mol). For an ideal gas mixture, the methane mole fraction equals its volume fraction when the component and mixture volumes are evaluated at the same temperature and pressure. Since the two-component mixture is an approximation, other constituents such as water vapour and hydrogen sulfide are neglected in the following expressions.
The methane mass fraction corresponding to the assumed composition is

$$w_{CH_4} = \frac{x_{CH_4} M_{CH_4}}{M_b} = \frac{x_{CH_4} M_{CH_4}}{x_{CH_4} M_{CH_4} + (1 - x_{CH_4}) M_{CO_2}} \tag{13}$$

where W_{CH_4} is the methane mass fraction, M_{CH_4} and M_{CO_2} are the molar masses of methane and carbon dioxide (kg mol^{-1}), respectively, and $\bar{M}_b$ is the mean molar mass of the assumed mixture, as introduced in Eqaution. (8). Thus, methane volume fraction must not be used directly as methane mass fraction when energy is calculated from a gas-mass estimate.

If the total mass of collected biogas is known, the chemical energy based on the lower heating value of methane is

$$E_{ch} = m_b w_{CH_4} LHV_{CH_4} \tag{14}$$

where E_{ch} is the chemical energy (J), m_b is the collected biogas mass (kg), and LHV_{CH_4} is the mass-specific lower heating value of methane (Jkg^{-1}). This equation assumes complete utilization of the methane energy, before accounting for the efficiency of any electrical conversion device. Its use with the present balance-derived readings is conditional upon those readings representing actual retained gas mass.

Alternatively, when biogas volume has been established at specified reference conditions, the corresponding chemical energy may be written as

$$E_{ch} = V_{b,ref} x_{CH_4} H_{CH_4,ref} \tag{15}$$

where $V_{b,ref}$ is the biogas volume (m^3) at the selected reference temperature and pressure and $H_{CH_4,ref}$ is the volumetric lower heating value of methane (Jm^{-3}) at the same reference conditions. The volume-based heating value is related to the mass-specific heating value, under the ideal gas approximation, by

$$H_{CH_4,ref} = \frac{P_{ref} M_{CH_4}}{R T_{ref}} LHV_{CH_4} \tag{16}$$

Equations (14) and (15) are equivalent when consistent gas composition, reference conditions, and heating-value conventions are used. They should not be mixed with an empirical coefficient lacking compatible physical units. In the present study, methane concentration, gas pressure, and standardized gas volume were not measured. Therefore, calculation of chemical energy requires an assumed methane fraction and, for a mass-based estimate, acceptance of the recorded mass increments as actual gas mass. All derived energy values must consequently be described as scenario-based estimates rather than measured fuel-energy yields. The subsequent subsection introduces electrical conversion efficiency to determine the corresponding theoretical electrical-energy potential.

2.4. Theoretical Electrical-Energy Potential

The electrical-energy potential of biogas depends on its combustible methane content and the performance of the device used to convert chemical energy into electricity. Theoretical electrical-energy estimates are therefore obtained by applying an assumed electrical conversion efficiency to the chemical energy associated with methane, rather than by equating biogas accumulation directly with electricity production [14],[15]. For a specified conversion system, the electrical energy is expressed as

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$$E_{\mathrm{el}} = \eta_{\mathrm{el}} E_{\mathrm{ch}} \quad (17)$$

where E_{el} is the theoretical electrical energy (J), E_{ch} is the chemical energy of methane (J), and η_{el} is the dimensionless electrical conversion efficiency ($0 \leq \eta_{el} \leq 1$). Using the mass-based chemical-energy relationship established in Section 2.3 gives

$$E_{\mathrm{el}} = \eta_{\mathrm{el}} m_{\mathrm{CH_4}} H_{\mathrm{CH_4}} \quad (18)$$

where m_{CH4} is the methane mass (kg) and H_{CH4} is the lower heating value of methane (J kg^{-1}). For a biogas sample of mass m_b with methane mass fraction w_{CH4}, Eq. (18) becomes

$$E_{\mathrm{el}} = \eta_{\mathrm{el}} m_b w_{\mathrm{CH_4}} H_{\mathrm{CH_4}} \quad (19)$$

For the illustrative two-component mixture of methane and carbon dioxide introduced in Section 2.2, the methane mass fraction can be determined from the methane mole fraction and constituent molar masses. Hence, Eq. (19) may also be written as

$$E_{\mathrm{el}} = \eta_{\mathrm{el}} m_b \frac{x_{\mathrm{CH_4}} M_{\mathrm{CH_4}}}{x_{\mathrm{CH_4}} M_{\mathrm{CH_4}} + \left(1 - x_{\mathrm{CH_4}}\right) M_{\mathrm{CO_2}}} H_{\mathrm{CH_4}} \quad (20)$$

Here X_{CH4} is the methane mole fraction, and M_{CH4} and M_{CO2} are the molar masses of methane and carbon dioxide, respectively. The expression assumes that other biogas components and water vapour are negligible, or that the stated composition refers to dry gas. It is therefore not a measured description of the biogas collected in this study.
For reporting the estimated energy in kilowatt-hours, the conversion is

$$E_{\mathrm{el}}\,(\mathrm{kWh}) = \frac{E_{\mathrm{el}}\,(\mathrm{J})}{3.6 \times 10^6} \quad (21)$$

An equivalent mean electrical power can be calculated only after defining an energy-delivery interval Δt, according to

$$\overline{P}_{\mathrm{el}} = \frac{E_{\mathrm{el}}}{\Delta t} \quad (22)$$

where $\bar{P}_{el}$ is mean electrical power (W) and Δt is the electricity-generation duration (s), not the ten-day digestion observation period. Without a defined generator operating interval, an electrical-power rating cannot be inferred from the accumulated gas readings.

For comparative scenario calculations, the same assumed methane composition, heating value and conversion efficiency may be applied to the three feedstocks. Under this common-assumption approach, the estimated electrical energies are directly proportional to the assumed gas masses; accordingly, their ordering is not independent evidence of electrical performance. Alternative methane fractions or efficiencies would change the numerical results and could change the ranking if they differed among feedstocks.

The present experiment did not measure methane concentration, collector pressure, standardized gas volume, or electrical output. Moreover, the observed balance increments from rigid collectors connected by tubing have not been independently validated as actual gas masses. Consequently, Eqs. (17)–(22) define conditional theoretical relationships. Their numerical application to the reported readings should be labelled scenario-based and should not be presented as measured or practically recoverable electrical energy. Any quantitative interpretation must also account for the energy required to operate gas-cleaning, compression, and generator systems, where relevant.

2.5. Assumptions and Limitations of the Theoretical Model

The theoretical estimation of electrical-energy potential is based on simplifying assumptions concerning biogas composition, thermodynamic behaviour, and energy-conversion efficiency. Biogas is approximated as a mixture of methane and carbon dioxide, with the methane fraction assumed rather than experimentally measured. The gas mixture is considered to obey the ideal gas equation, while its chemical energy is evaluated using the lower heating value of methane. A constant electrical conversion efficiency is adopted to estimate the proportion of chemical energy potentially recoverable as electricity [[4],[14],[15]].

The principal limitations arise from the absence of experimental measurements of methane concentration, collector pressure, and electrical conversion efficiency. Furthermore, the gas collectors remained connected to the digesters during weighing, introducing possible uncertainties associated with tubing forces and pressure variations. Consequently, the recorded balance changes cannot be independently verified as actual accumulated gas masses. The theoretical electrical-energy estimates are therefore conditional on the validity of these measurements and the adopted assumptions. They are

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intended for preliminary comparison of the three animal wastes and should not be interpreted as experimentally measured electricity generation or validated electrical-energy yields.

3. Methodology

This section describes the materials, experimental apparatus, and procedures employed to investigate biogas accumulation from cow dung, goat dung, and poultry droppings under ambient anaerobic digestion conditions. It presents the preparation of the substrates, digester configuration, gas-collection procedure, and measurement of experimental parameters. The methods used for processing the recorded data and estimating theoretical electrical-energy potential are also described.

3.1. Materials

The materials for this work are listed in table 1, are explained.

Table 1. Materials and apparatus used for the anaerobic digestion experiment and their functions

Material/apparatus	Specification or quantity	Use in the experiment
Cow dung	Fresh animal waste; sample A	Organic feedstock for digester A
Goat dung	Fresh animal waste; sample B	Organic feedstock for digester B
Poultry droppings	Fresh animal waste; sample C	Organic feedstock for digester C
Water	5.00 kg per digester	Dilution and preparation of each waste slurry
Plastic batch digesters	Three airtight containers, 10 L each	Anaerobic digestion of the individual waste slurries
Gas collectors	Three rigid, airtight containers, 1L each	Retention of gas admitted from each digester
Drip-transfusion tubes	Three connecting tubes fitted with valves	Transfer of gas between digesters and collectors and control of admission
Adhesive sealant	Type not specified	Sealing joints to limit gas leakage
Digital balance	Model and resolution not reported	Recording changes in gas-collector balance readings
Thermometer	Type and resolution not reported	Measurement of ambient laboratory temperature
Retort stands and clamps	Specifications not reported	Supporting and positioning the apparatus

The materials used in this investigation comprised cow dung, goat dung, poultry droppings, water, and laboratory apparatus for anaerobic digestion and biogas collection. Fresh samples of the three animal wastes were obtained from local farms in Jimeta-Yola, Adamawa State, Nigeria. The samples were designated A, B, and C for cow dung, goat dung, and poultry droppings, respectively. Water was used to prepare the feedstock mixtures at a uniform waste-to-water mass ratio of 2:5.

The experimental apparatus consisted of three airtight plastic containers, each having a capacity of 10L, which served as batch anaerobic digesters. Three rigid, airtight gas collectors, each with a nominal capacity of 1L, were used to collect the biogas generated from the corresponding digesters. Each digester was connected to its gas collector through a drip-transfusion tube fitted with a control valve to regulate gas transfer. Adhesive sealant was applied to the connecting joints to minimize gas leakage. Digital balances were used to monitor changes in the apparent mass of the gas collectors, while a thermometer was used to measure the ambient laboratory temperature. Retort stands and clamps provided mechanical support for the experimental arrangement.

The experiment was conducted in the Physics Laboratory of Adamawa State Polytechnic, Yola, Nigeria. The initial masses of the empty gas collectors were 61g, 60g, and 64g for samples A, B, and C, respectively. These values served as the initial mass references for monitoring the changes in balance readings during the digestion period.

3.2. Method

Fresh cow dung, goat dung and poultry droppings were collected from local farms in Jimeta-Yola, Adamawa State, Nigeria, and designated samples A, B and C, respectively. Each feedstock was mixed thoroughly before loading. Three separate 10-L plastic batch digesters were prepared, and each received 2.00kg of its assigned animal waste and 5.00kg of water, giving a feedstock-to-water mass ratio of 2:5. No external inoculum was added. The initial slurry pH values recorded for cow dung, goat dung and poultry droppings were 6.80, 6.70 and 6.40, respectively.

Each digester was sealed and connected to a rigid, airtight 1-L gas collector through a drip-transfusion tube fitted with a control valve. Adhesive sealant was applied at the joints to prevent gas leakage. The collectors were supported continuously on digital balances and remained attached to their corresponding digesters during observation. The initial collector masses were 61g (A), 60g (B) and 64g (C). Figure 1 illustrates the gas-transfer and measurement arrangement, while Figure 2 reproduces a photograph of the apparatus reported in the original study.

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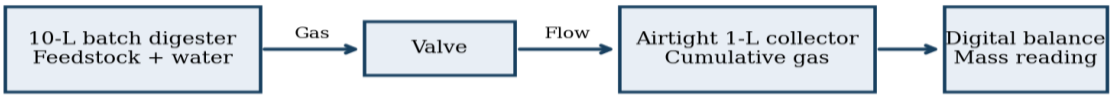


Figure 1. Schematic arrangement of the batch digester, valved connection, sealed gas collector and digital-balance measurement system.



Figure 2. Photograph of a batch digester connected to the gas collector and digital balance (original experimental photograph).

After loading and sealing, the digesters were allowed to ferment for 48hr before routine measurements began. The experiment was conducted under ambient conditions in the Physics Laboratory, Adamawa State Polytechnic, Yola. The manuscript describes a ten-day monitoring period following the initial fermentation stage; no independent temperature control or mechanical mixing protocol was reported.

At each observation, the appropriate valve was opened for approximately 3–5s to admit gas from the digester into its collector and then closed. The collectors were not emptied between observations. The digital-balance indication was recorded while the collector remained supported on the balance and the connecting tubing remained attached. Eight readings were obtained daily at hourly intervals between 10:00 and 17:00. Laboratory temperature was recorded at the same observation times. Since gas pressure nor gas composition were assumed, the observed balance increments were treated as apparent gas-accumulation readings, rather than independently verified masses of biogas.

The original experiment recorded successive balance changes by taking the balance after each observation and adding each newly indicated increment to the preceding cumulative value. The resulting series was summarized using the cumulative-reading relationship in Eqaution. (2) and the apparent-mass definition in Equation (3) of the theoretical framework. For each feedstock and digestion day, the eight cumulative readings were averaged as defined by Equation (4). The eight temperature observations were similarly averaged to obtain the mean daily laboratory temperature. Because the daily observations were means of cumulative readings from collectors that retained gas, they were not added together to obtain a ten-day total. The day-10 daily mean was taken as the final descriptive comparison.

The theoretical electrical-energy assessment was linked to the mass-based chemical-energy and electrical-conversion expressions developed in Sections 2.3 and 2.4. Any numerical estimate necessarily assumes that an apparent collector-mass increase represents the mass of retained biogas, together with stated methane composition, methane lower heating value and electrical conversion efficiency.

4. Result and Discussion

This section displays the result of the research work and explains it.

4.1. Results

This section presents the experimental results obtained from the anaerobic digestion of cow dung, goat dung and poultry droppings under ambient laboratory conditions. The results include the initial loading conditions, mean daily temperature, cumulative gas-collector mass readings and conditional theoretical electrical-energy estimates. The original experimental readings are retained without modification, while the theoretical electrical-energy values are calculated

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using the assumptions specified in Section 2. The results are presented in Tables 2–6 without detailed interpretation, which is reserved for Section 4.2.

4.1.1. Initial experimental conditions

The initial loading conditions and measured slurry pH for the three digesters are presented in Table 2.

Table 2. Initial loading conditions and measured pH.

Digester	Feedstock	Feedstock (kg)	Water (kg)	Initial pH
A	Cow dung	2.00	5.00	6.80
B	Goat dung	2.00	5.00	6.70
C	Poultry droppings	2.00	5.00	6.40

4.1.2. Variation of gas accumulation with digestion time

Table 3 presents the mean daily laboratory temperature and the mean cumulative gas-collector mass readings recorded during the ten-day observation period.

Table 3. Mean daily temperature and cumulative gas-collector mass readings.

Day	Temperature (°C)	Cow dung (kg)	Goat dung (kg)	Poultry droppings (kg)
1	32.79	0.00231	0.00142	0.00187
2	33.53	0.00264	0.00155	0.00270
3	33.38	0.00301	0.00210	0.00323
4	32.63	0.00443	0.00285	0.00490
5	33.50	0.00568	0.00372	0.00598
6	32.75	0.00663	0.00448	0.00685
7	32.63	0.00715	0.00490	0.00793
8	33.00	0.00723	0.00483	0.00963
9	32.82	0.00734	0.00480	0.01020
10	32.34	0.00741	0.00480	0.01140

The temporal variation of the mean cumulative readings is illustrated in Figure 3.

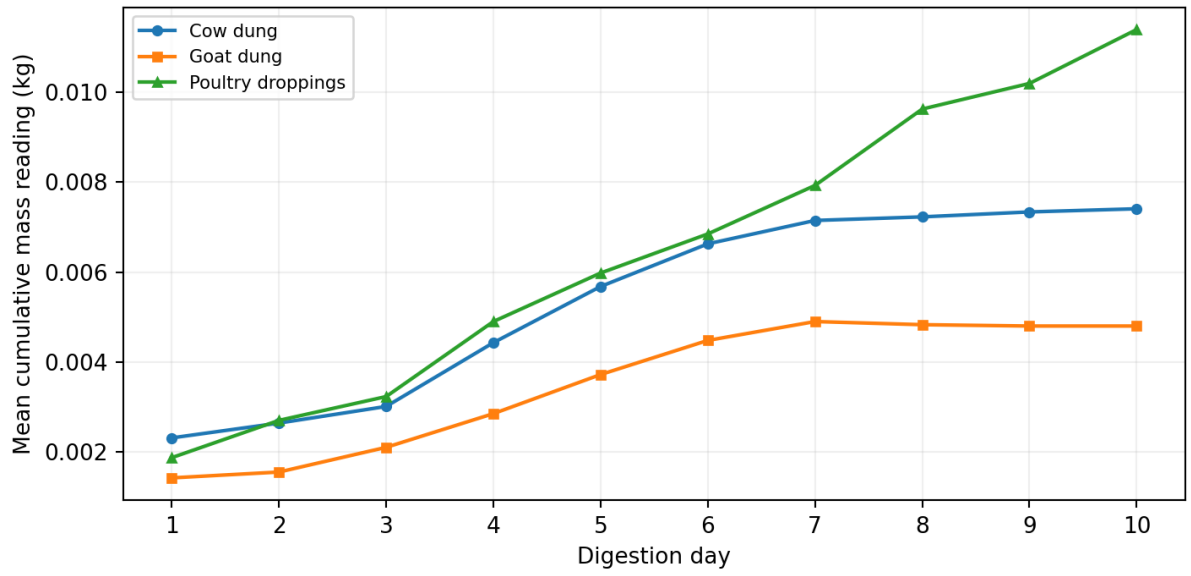


Figure 3. Variation of mean cumulative gas-collector mass readings with digestion time for the three animal wastes.

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The daily readings represent averages of eight cumulative observations rather than separate daily gas quantities. Consequently, the values were not summed across the ten-day observation period.

4.1.3. Parameters for theoretical electrical-energy estimation

The quantities required for evaluating the theoretical electrical-energy potential of the accumulated biogas are presented in Table 4.

Table 4. Parameters required for theoretical electrical-energy estimation.

Parameter	Symbol	Value or experimental status
Methane mole fraction	$x(CH_4)$	0.60
Carbon dioxide mole fraction	$x(CO_2)$	0.40
Methane mass fraction	$w(CH_4)$	0.35350
Methane lower heating value	$H(CH_4)$	50 MJ kg^{-1}
Electrical conversion efficiency	$\eta(el)$	0.25
Collector internal pressure	P	Not measured
Standardized biogas volume	V(b)	Not measured
Methane concentration	$x(CH_4)$	Not measured experimentally

The methane mass fraction was calculated using the assumed methane–carbon dioxide composition. Based on these assumptions, the theoretical electrical-energy conversion factor is approximately 4.41878×10^6 J kg^{-1} of assumed biogas.

4.1.4. Theoretical electrical-energy estimates during digestion

Table 5 presents the conditional theoretical electrical-energy estimates calculated from the mean cumulative mass readings for the three substrates over the ten-day observation period.

Table 5. Calculated theoretical electrical-energy estimates for cow dung, goat dung and poultry droppings.

Day	Cow dung (kJ)	Goat dung (kJ)	Poultry droppings (kJ)
1	10.21	6.27	8.26
2	11.67	6.85	11.93
3	13.30	9.28	14.27
4	19.58	12.59	21.65
5	25.10	16.44	26.42
6	29.30	19.80	30.27
7	31.59	21.65	35.04
8	31.95	21.34	42.55
9	32.43	21.21	45.07
10	32.74	21.21	50.37

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The variation of the conditional theoretical electrical-energy estimates with digestion time is presented in Figure 4.

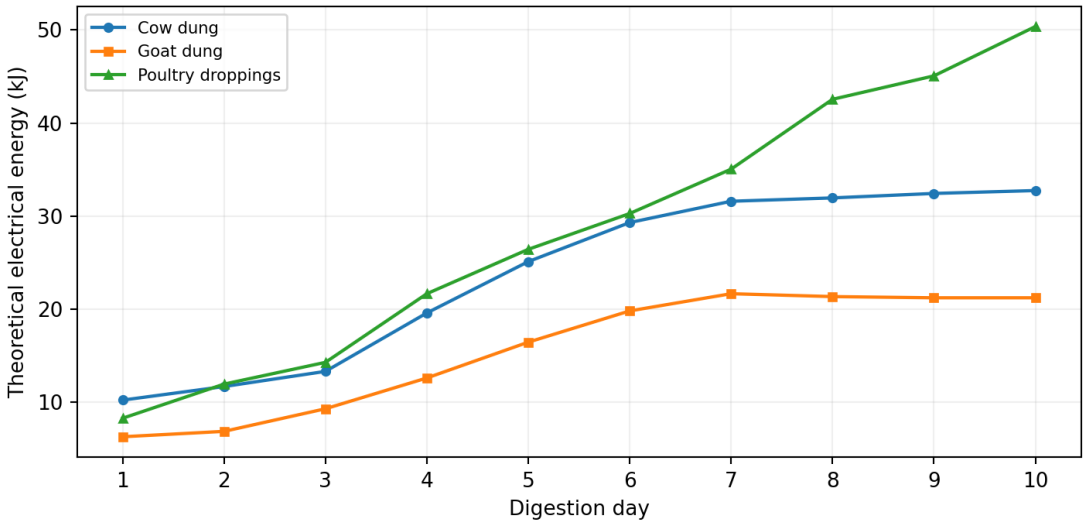


Figure 4. Variation of conditional theoretical electrical-energy estimates with digestion time for the three animal wastes.

The values in Table 5 and Figure 4 were determined using the same assumed methane composition, heating value and electrical conversion efficiency for all three substrates. The estimates are based on the apparent cumulative mass readings and are not measured electrical-energy outputs.

4.1.5. Final comparison of theoretical electrical-energy potential

The day-10 cumulative mass readings and their corresponding theoretical electrical-energy estimates are presented in Table 6.

Table 6. Final comparison of apparent gas accumulation and conditional theoretical electrical-energy estimates on day 10.

Feedstock	Apparent gas mass (kg)	Theoretical energy (kJ)	Theoretical energy (kWh)
Cow dung	0.00741	32.74	0.00910
Goat dung	0.00480	21.21	0.00589
Poultry droppings	0.01140	50.37	0.01399

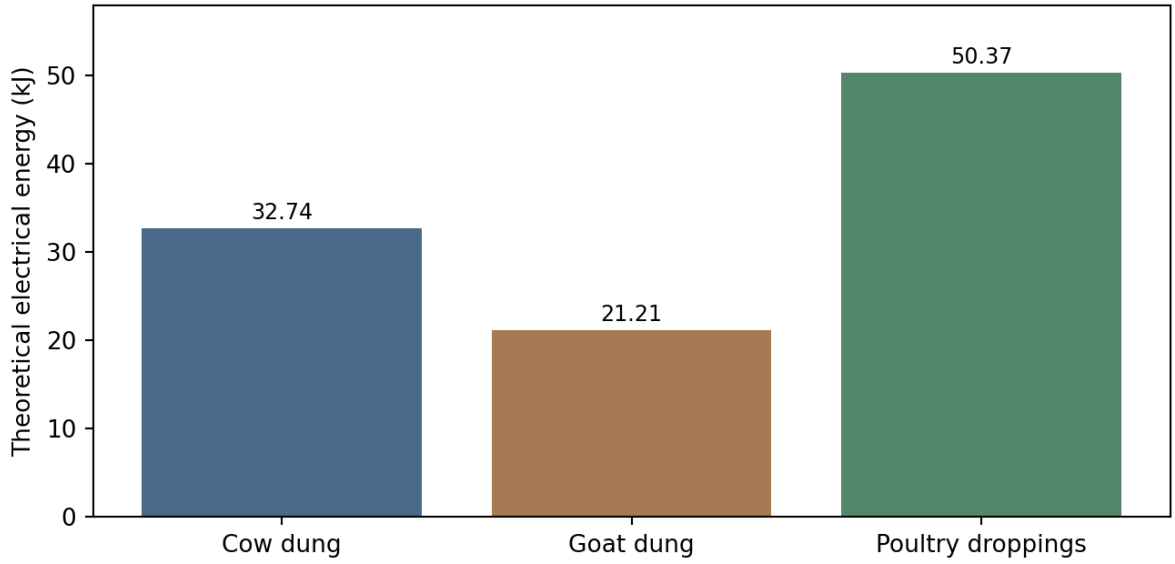


Figure 5. Comparison of conditional theoretical electrical-energy estimates for the three animal wastes at the end of the ten-day observation period.

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The theoretical electrical-energy estimates presented in Tables 5 and 6 were obtained using the apparent gas-collector mass readings and common assumed energy-conversion parameters. Since gas composition, internal collector pressure and actual electrical output were not measured, the calculated values are conditional estimates rather than experimentally verified electrical-energy yields.

4.2 Discussion

The results presented in Table 3 and Figure 3 reveal differences in the short-term gas accumulation recorded from cow dung, goat dung and poultry droppings under ambient anaerobic digestion conditions. Poultry droppings recorded the highest day-10 cumulative mass reading of 0.01140 kg, followed by cow dung (0.00741 kg) and goat dung (0.00480 kg). The poultry reading exceeded those of cow dung and goat dung by approximately 53.8% and 137.5%, respectively. These differences may be associated with variations in the organic composition and biodegradability of the substrates. The observed ranking agrees with previous investigations reporting relatively high biogas production from poultry wastes [9],[10],[11], although differences in experimental conditions and measurement procedures prevent direct quantitative comparisons.

The accumulation patterns varied throughout the digestion period, with poultry droppings showing a continuous increase, while cow dung approached a plateau after day 7. Ambient temperature ranged from 32.34 to 33.53 °C, while the initial slurry pH varied between 6.40 and 6.80. Although these parameters influence microbial activity during anaerobic digestion [4],[6],[13], their individual contributions could not be established because temperature was not independently controlled and pH was not monitored throughout the experiment. The slight decline in the cumulative goat-dung readings after day 7 may reflect measurement variability rather than negative gas production.

The conditional theoretical electrical-energy estimates in Tables 5 and 6 followed the recorded accumulation patterns. Assuming a methane mole fraction of 0.60 and electrical conversion efficiency of 25%, the estimated day-10 electrical energies were 50.37 kJ for poultry droppings, 32.74 kJ for cow dung and 21.21 kJ for goat dung. These results illustrate the theoretical relationship between biogas accumulation and potential electricity generation, consistent with previous investigations of biogas-based electricity recovery [14],[15]. However, the estimates depend on assumed gas composition and conversion efficiency and should not be interpreted as experimentally verified electrical-energy yields.

The research gap addressed by this study concerns the limited characterization of short-term gas-accumulation patterns under the specific ambient batch-digestion and substrate-loading conditions employed in the experiment, together with their conditional relationship to theoretical electrical-energy potential. Although earlier studies have compared similar animal wastes [9],[10],[11], the present investigation provides additional observations from a ten-day digestion system using equal substrate masses and a common gas-collection arrangement. Its distinctive contribution lies in integrating the recorded short-term accumulation patterns with a mass-based theoretical electrical-energy framework, while explicitly distinguishing the experimental readings from estimated electrical output. Thus, the novelty is an incremental experimental and analytical contribution rather than a new anaerobic digestion process or electricity-conversion model.

The principal limitations include the absence of methane-composition and collector-pressure measurements, uncertainties associated with determining gas mass from rigid collectors connected through tubing, and the lack of independent digester replication. Consequently, the observed differences cannot be regarded as statistically established feedstock effects, and the calculated electrical-energy values remain conditional. Nevertheless, the combined assessment provides preliminary information relevant to animal-waste utilization and identifies the measurements required for more reliable evaluation of small-scale biogas-to-electricity systems.

5. Conclusion

5.1. Conclusion

This study investigated short-term biogas accumulation and theoretical electrical-energy potential from cow dung, goat dung and poultry droppings under ambient anaerobic digestion conditions. The results showed that poultry droppings recorded the highest day-10 cumulative gas-collector mass reading of 0.01140 kg, followed by cow dung (0.00741 kg) and goat dung (0.00480 kg). Under the assumed methane mole fraction of 0.60 and electrical conversion efficiency of 25%, the corresponding conditional theoretical electrical-energy estimates were 50.37, 32.74 and 21.21 kJ, respectively. These findings indicate that poultry droppings exhibited the greatest recorded short-term accumulation under the experimental conditions. However, the absence of gas-composition and pressure measurements, together with uncertainties in the balance-derived gas masses, prevents the calculated values from being regarded as verified biogas yields or electrical-energy outputs.

5.2. Recommendations

Future investigations should employ independently replicated digesters, calibrated gas-measurement systems and continuous monitoring of temperature, pH and collector pressure. Methane composition, total solids and volatile solids should also be determined to permit standardized biogas-yield and energy assessments. Extending the digestion period

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and conducting experimental electricity-generation tests would provide a more reliable basis for evaluating the practical energy potential of the selected animal wastes.

5.3. Contribution to Knowledge

The study contributes preliminary experimental information on the ten-day gas-accumulation patterns associated with cow dung, goat dung and poultry droppings under comparable ambient batch-digestion conditions. It further demonstrates how recorded accumulation data can be incorporated into a mass-based theoretical framework for estimating conditional electrical-energy potential. By distinguishing apparent gas-collector mass readings from verified biogas quantities and theoretical energy estimates from measured electricity, the investigation identifies important methodological requirements for reliable evaluation of small-scale animal-waste energy systems.

5.4. Specific Novelty Statement

The specific novelty of this work lies in integrating short-term experimental gas-accumulation observations from three animal wastes with a conditional theoretical assessment of their electrical-energy potential under a common ambient batch-digestion configuration. Unlike previous investigations emphasizing longer-duration biogas-volume measurements, the present study examines ten-day accumulation patterns obtained using rigid gas collectors and relates the recorded mass changes to theoretical energy estimates under explicitly stated methane-composition and conversion-efficiency assumptions. This integrated approach provides an incremental experimental and analytical contribution while identifying the measurement limitations that must be resolved before practical electricity-generation potential can be established.

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Author Contributions: Y.D. Musa: Conceptualization, Formal analysis, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing-original draft, Writing-review, investigstion and editing. A. Lawan: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Writing-original draft, Writing-review and editing. A. I. Mohammed: Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing-original draft, Writing-review and editing. Z. Abubakar: Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing-original draft, Writing-review and editing. R. Yakubu: Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing-original draft, Writing-review and editing. Y. M. Shingu: Data curation, Formal analysis, Investigation, Methodology, Resources, Visualization, Writing-original draft, Writing-review and editing

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