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Research Article

Experimental assessment of domestic biogas production from organic waste through anaerobic digestion in Chad

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Abstract. Environmental degradation and health concerns. In this context, the valorisation of organic waste through anaerobic digestion represents a promising alternative for sustainable household energy production. This study presents an experimental assessment of domestic biogas production from organic waste under local conditions in Chad. A pilot-scale anaerobic digestion system was designed and operated for a period of 30 days. The digester was fed with a mixture of vegetable organic waste and fresh cow dung used as inoculum. Key operational parameters, including temperature and pH, were regularly monitored throughout the digestion process. The system was designed to meet the cooking energy needs of a household of eight persons, and the technical feasibility of biogas production was evaluated. The experimental results showed that biogas production started from the tenth day of fermentation and increased progressively with the hydraulic retention time. The pH remained within a range favourable to methanogenic activity, while temperature variations were compatible with mesophilic digestion conditions. The observed biogas production confirmed the methanogenic potential of the selected organic substrates and demonstrated the suitability of the proposed low-cost digester for domestic energy applications. Biogas volume increases with daily feeding (1/60 of the useful volume) and a retention time of 30 days, reaching a maximum volume of 1,2 m³. This can reduce daily consumption by approximately 0,2 m³ of butane, 1,24 kg of charcoal, and 2,5 kg of firewood.The findings indicate that anaerobic digestion of household organic waste can contribute to sustainable energy supply, waste management improvement and reduction of pressure on forest resources in Chad. This study provides practical evidence supporting the deployment of small-scale biogas systems in similar socio-economic contexts.

Keywords: Anaerobic digestion, Chad Domestic biogas, , Organic waste

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1. Introduction

Domestic energy plays a central role in improving living standards and socio-economic development in low- and middle-income countries, as it directly supports essential household activities such as cooking, heating and lighting. In Sub-Saharan Africa, firewood and charcoal account for the majority of domestic energy consumption, particularly for cooking purposes, due to their affordability and widespread availability (Cherni & Hill, 2009). This heavy dependence on wood-based energy systems has significant environmental consequences. Unsustainable fuelwood harvesting is widely recognised as a major driver of deforestation and forest degradation, contributing to biodiversity loss, soil erosion and sanitary issues. Numerous studies have linked prolonged exposure to biomass smoke to respiratory infections, chronic obstructive pulmonary disease and cardiovascular illnesses, with women and young children being the most affected due to their greater exposure during cooking activities (Bonjour et al., 2013). As a result, addressing domestic energy needs through cleaner and more sustainable alternatives is therefore a critical priority for developing countries.

The generation of organic waste has increased significantly in developing countries as a result of rapid population growth, urbanisation and changing consumption patterns. Household food waste, market residues and agro-processing by-products constitute a major fraction of municipal solid waste streams. However, waste management systems in many low-income countries remain inadequate, leading to uncontrolled disposal practices such as open dumping and open burning. These practices contribute to environmental pollution, groundwater contamination and greenhouse gas emissions, while also creating serious public health risks through the proliferation of disease vectors (Kaza et al., 2018). Organic waste is particularly problematic due to its high biodegradability, which results in uncontrolled methane emissions when decomposed under unmanaged anaerobic conditions. Despite these challenges, organic waste represents a valuable and largely underexploited renewable resource. Rich in biodegradable organic matter, it can be converted into useful forms of energy through appropriate treatment technologies. Waste-to-energy

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approaches offer an opportunity to transform organic waste from an environmental burden into a resource capable of contributing to energy supply, improved sanitation and resource efficiency. In this context, the valorisation of organic waste aligns with circular economy principles by simultaneously addressing waste management challenges and domestic energy needs (Vergara & Tchobanoglous, 2012).

Anaerobic digestion has emerged as a promising waste-to-energy technology capable of simultaneously addressing domestic energy shortages and organic waste management challenges in developing countries. This biological process converts biodegradable organic matter into biogas, a renewable energy carrier mainly composed of methane, while producing a stabilised digestate suitable for agricultural use. Compared with thermal waste treatment methods, anaerobic digestion is particularly attractive for household-scale applications because it operates under moderate temperature conditions, requires relatively low capital investment and can be implemented using locally available materials (Weiland, 2010). Moreover, anaerobic digestion contributes to greenhouse gas mitigation by capturing methane that would otherwise be released during uncontrolled waste decomposition, while reducing reliance on traditional biomass fuels for cooking. Several studies have demonstrated that small-scale anaerobic digesters can effectively process household organic waste, animal manure and agricultural residues under mesophilic conditions, delivering stable biogas yields when key operational parameters such as pH and temperature are adequately controlled (Bista et al., 2023).

Despite the recognised potential of anaerobic digestion for waste-to-energy applications, significant scientific and practical gaps remain, particularly in least developed countries. In Chad, domestic energy supply is still dominated by fuelwood and charcoal, while organic waste management remains largely informal and inefficient (FAO, 2017; World Bank, 2022). Although several studies have demonstrated the technical feasibility of biogas production in controlled or large-scale systems, experimental evidence focusing on low-cost, household-scale digesters under local climatic and socio-economic conditions is scarce (Weiland, 2010; Scarlat et al., 2018). Existing biogas initiatives in Chad are mostly limited to pilot or institutional projects, with limited peer-reviewed data on system performance, operational stability and suitability for domestic energy needs (Hosseini & Wahid, 2014). Moreover, most studies conducted in Sub-Saharan Africa focus on agricultural or community-scale digesters, leaving household-level applications underexplored (Bond & Templeton, 2011). Addressing these gaps requires locally grounded experimental assessments capable of informing scalable and context-appropriate biogas solutions.

Against this background, the present study aims to provide an experimental assessment of domestic biogas production from organic waste through anaerobic digestion under local conditions in Chad. Specifically, the study seeks to evaluate the methanogenic potential of selected household organic substrates, assess the technical performance and operational stability of a low-cost pilot-scale digester, and examine the suitability of the produced biogas for domestic cooking applications. By generating locally grounded experimental data, this work intends to fill existing knowledge gaps regarding household-scale anaerobic digestion systems. The findings are expected to support the promotion of sustainable waste-to-energy solutions while contributing to improved domestic energy access, environmental protection and resource recovery in similar developing-country contexts.

2. Experiment

2.1 Study area and experimental context

The experimental study was conducted in Chad, a Central African country characterised by high dependence on traditional biomass for domestic energy supply and limited access to modern renewable energy technologies. The pilot anaerobic digestion system was installed and operated under real local conditions within a technical workshop environment dedicated to renewable energy experimentation. The study area experiences a tropical climate with high ambient temperatures, conditions generally favourable to mesophilic anaerobic digestion processes. The experimental work was carried out over a 30-day period, reflecting typical hydraulic retention times for small-scale household digesters. The system was designed to simulate domestic operating conditions, with particular emphasis on low-cost construction materials, locally available organic substrates and simplified operational procedures. This contextual setup enabled the evaluation of biogas production performance under conditions representative of potential household adoption in Chad and similar Sub-Saharan African settings.

2.2 Feedstock collection and characterisation

The anaerobic digestion experiment was conducted using locally available organic substrates collected from domestic and agro-organic sources. The primary feedstock consisted of mixed vegetable waste, including leafy residues and food preparation discards generated from household activities. Fresh cow dung was used as a co-substrate and biological inoculum due to its high concentration of active methanogenic microorganisms, which facilitate process start-up and enhance biogas yield stability (Weiland, 2010). The use

Figure 1. raw materials

of animal manure as inoculum is widely recommended in small-scale anaerobic digestion systems to improve microbial diversity and buffering capacity (Bond & Templeton, 2011).

Prior to digestion, the collected organic waste underwent manual sorting to remove non-biodegradable impurities, followed by mechanical size reduction to increase the surface area available for microbial degradation. Such pre-treatment operations are known to enhance hydrolysis efficiency and overall methane production potential (Mata-Alvarez et al., 2014). The prepared substrates were then diluted with water to obtain a homogeneous slurry suitable for wet anaerobic digestion. Physico-chemical characterisation of the feedstock was performed to determine key parameters influencing biogas production. Total solids (TS) and moisture content were measured through oven-drying at 105 °C until constant mass, following standard biomass analysis procedures (APHA, 2017). Organic matter content, expressed as volatile solids (VS), was determined by calcination of dried samples in a muffle furnace at high temperature. These parameters are widely used to evaluate substrate biodegradability and methane generation potential in anaerobic digestion studies (Li et al., 2011).

2.3 Design of the anaerobic digester

The pilot anaerobic digestion system used in this study was designed as a low-cost, small-scale unit suitable for domestic biogas production under local conditions. The digester consisted of a metallic dual-drum reactor configuration fabricated from two cylindrical steel barrels, each with a nominal capacity of 200 L as shown in figure 2 . The first drum functioned as the primary fermentation chamber, while the second served as a secondary digestion and digestate displacement unit, enabling improved substrate retention and gas recovery efficiency. Both reactors were hydraulically connected using polyvinyl chloride (PVC) piping to ensure substrate transfer and hydraulic balance. The influent inlet was installed at the lower section of the primary drum through a PVC feeding pipe, allowing the introduction of pre-mixed organic slurry. An outlet pipe connected to the secondary drum facilitated digestate overflow and discharge after the hydraulic retention period.

Gas collection was achieved through an airtight outlet valve installed on the secondary reactor cover and connected to a flexible gas conveyance tube. A rubber inner tube was used as a low-pressure gas storage chamber, functioning as a gasometer for temporary biogas accumulation. Additional safety and operational accessories included gas valves, hose clamps, sealing joints and water traps to prevent gas leakage and moisture transfer. The entire system was designed using locally available materials to ensure affordability, ease of construction and replicability for household-scale applications.

2.4 Experimental procedure

The anaerobic digestion experiment was conducted under batch operating conditions using the pilot-scale dual-drum digester described in figure 3. Prior to loading, the prepared organic substrates were mixed with fresh cow dung inoculum to enhance microbial activity and accelerate methanogenic start-up. The substrate–inoculum mixture was diluted with water to obtain a homogeneous slurry suitable for wet anaerobic digestion, ensuring adequate mass transfer and microbial contact. Such dilution practices are widely recommended to optimise substrate biodegradability and prevent process inhibition due to excessive solids

Figure 2 Reactor-fermenter

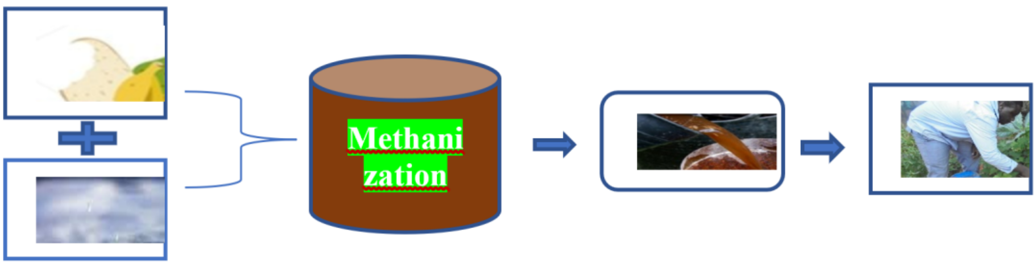

Figure 3. Experimental procedure

concentration (Mata-Alvarez et al., 2014) The digester was loaded manually through the influent inlet pipe until the working volume was reached. Care was taken to ensure airtight sealing of all reactor openings to maintain strict anaerobic conditions throughout the digestion period. The system was then operated without further feeding, following a batch digestion approach commonly applied in pilot and laboratory-scale studies (Li et al., 2011).

The experimental digestion process was monitored over a 30-day hydraulic retention time (HRT), corresponding to typical operational ranges for mesophilic small-scale digesters treating organic waste and animal manure mixtures (Weiland, 2010). During this period, no mechanical agitation was applied; mixing occurred naturally through gas formation and substrate displacement. This operational configuration was selected to simulate simplified household digester conditions and evaluate biogas production performance under realistic low-technology settings.

2.5 Operating parameters monitoring

The performance of the anaerobic digestion process was evaluated through regular monitoring of key physico-chemical and operational parameters known to influence biogas production. Temperature was continuously monitored throughout the digestion period using a digital temperature sensor inserted directly into the reactor slurry. The probe was connected to a recording device to ensure accurate tracking of thermal variations within the digester. Temperature control is essential in anaerobic digestion, as microbial activity and methane yield are strongly dependent on thermal conditions, particularly within the mesophilic range. The pH of the digesting substrate was measured periodically using a portable digital pH meter (model C-600). Samples were collected from the digester at defined intervals and analysed immediately to avoid alterations due to atmospheric exposure. Monitoring pH evolution is critical for assessing process stability, since methanogenic microorganisms are highly sensitive to acidic or alkaline fluctuations.

In addition to temperature and pH, biogas production was monitored qualitatively through visual observation of gas accumulation in the storage chamber and through combustion tests. A manometer was also integrated into the system to indicate internal gas pressure variations. Supporting components such as gas filters and water traps were installed to ensure gas purity and prevent moisture transfer into the storage unit

Figure 4. Temperature sensor (a), pH meter model C-600 (b), pressure gauge (c)

2.6 Biogas production assessment

Biogas production from the anaerobic digester was assessed using qualitative and semi-quantitative evaluation methods adapted to the pilot-scale and low-instrumentation context of the study. Gas accumulation was monitored through visual observation of the storage unit connected to the reactor. A rubber inner tube was used as a low-pressure gasometer for temporary biogas storage. The progressive inflation of the chamber provided a direct indication of gas generation and relative production dynamics over the digestion period.

Due to the absence of calibrated volumetric gas measurement devices, biogas yield was not quantified using flow meters or displacement systems. Instead, production was evaluated through indirect indicators, including gas pressure build-up observed via the integrated manometer and physical expansion of the storage chamber. To confirm the combustible nature and methane presence within the produced gas, combustion tests were conducted periodically. The stored biogas was channelled to a burner outlet, where ignition trials were performed. The appearance of a stable blue flame was considered indicative of methane-rich biogas and satisfactory digestion performance. This qualitative validation approach is commonly applied in pilot and household-scale biogas studies where simplified monitoring systems are used.

2.7. Biogas sizing and production parametrs

The optimal parameters below allow the sizing so that the 0.4 m3 digester can produce sufficient biogas to meet cooking energy needs.

Digester sizing

The digester is composed of two 200-liter drums, so the total volume (Vt) of the digester is 400 liters. For optimal efficiency, it is preferable not to completely fill the drums, leaving space for the gas. A filing of 80 % would therefore give a usual volume (Vu) of the 320 liters for the material to be digested (M. Casallas-Ojeda et al., 2022) :

$$V_u = 80\% \text{ x } V_t \qquad (1)$$

The volumetric flow is given by equation (M. Casallas-Ojeda et al., 2022) :

$$Q = \frac{Vu}{TRH} \quad (2)$$

Where: Q flow rate ; Vu useful volume; TRH = hydraulic retention time (30 days).

Daily Digester Loading

Regular feeding, often with fresh materials, begins about ten days after gas production starts. The total volume corresponds to 1/60 of the useful volume of the digester. For daily loading, we adopted the recirculation system, which consist of reusing a portion of the digestate for the new load. This reduces water quantities and can increase biogas production.

We used 10% of the digestate for each new load to dilute the substrate :

$$Vd = 10\% \text{ x } V \quad (3)$$

Potential Biogas Production

The potential biogas production depends on the useful volume and the daily biogas production per unit volume of digester, determined in the laboratory as Ps=0.18m3/m3.dig/day (average experimental value):

$$V_b = V_u \text{ x } P_s \quad (5)$$

Where: Vs biogas volume ; Vu useful volume; Ps daily biogas productivity per unit volume of digester.

Biogas Storage

We stored the produced biogas in an inner tube. The volume (Vbiogaz) is calculated from the relative pressure (ΔP) and the dead volume (Vchambre). Neglecting temperature influence, the biogas volume was estimated each time the inner tube was full using the formula:

$$V_{biogaz} = Vchambre \text{ x } \Delta P \quad (6)$$

Where: Vchambre volume of the inner tube, ΔP relative atmospheric pressure of the biogas in the inner tube

The torus section representing the inner tube is a circle of radius r. The volume of the inner tube was calculated using:

$$Vtorc = \boldsymbol{2\pi^2 . r^2 . R} \quad (7)$$

biogas yield stability (Weiland, 2010). The use of animal manure as inoculum is widely recommended in small-scale anaerobic digestion systems to improve microbial diversity and buffering capacity (Bond & Templeton, 2011).

2.8. Physicochemical Characterization of Raw Materials

Dry Matter (DM)

The dry matter content (DM) is determined by weight difference after total dehydration at 105°C in the case of cow dung, kitchen waste, and fish waste over 24 hours. Applying a lower temperature during the dehydration step, corresponding to the measurement protocol generally applied to organic waste, is necessary. The dry matter value of each sample is obtained using the following relation (Habchi et al., 2022) :

$$DM(\%) = \frac{M2-M}{M1} x100 \quad (8)$$

Where: M mass of the crucible (g), M mass of the sample before dehydration (g), M_2: mass of the crucible + sample after dehydration (g)

Moisture content (H)

The moisture of each mixture is measured as quickly as possible. 100g of each substrate is placed in an oven at 105±2°C for 24 hours according to standard NF M03-002. Moisture content is calculated using the relation (Aguirre et al. 2023) :

$$H(\%) = \frac{M1-M2}{M1} \quad (9)$$

Where H (%): percentage of moisture, M_1=Minitial: mass of the sample before drying, M_2=Mfinal: mass of the sample after drying

Organic Matter Content

The method considered for determining the organic matter content :

Weigh 20g of each substrate and place in an oven for 24 hours at 105°C. Then calcine 3g of the pre-dried samples at 600°C for at least 6 hours in a muffle furnace, and determine the dry residue. The organic matter (OM) or total volatile solids (TVS) content is obtained by weight difference between the dry waste and the calcined waste at 550°C until constant weight for at least 6 hours.

$$OM(\%) = \frac{mass\ of\ dry\ sample - mass\ of\ calcined\ sample}{mass\ of\ dry\ sample} \times 100 \qquad (10)$$

The total OM of the co-substrate mixture is given by:

$$OMtotal(\%) = \frac{(mass\ of\ comp1\ x\ OM\ of\ substrate1)+(mass\ of\ comp2\ x\ OM\ of\ substrate2}{total\ mass\ of\ mixture} \qquad (11)$$

Organic Load

The organic load (OL) introduced over thirty (30) days in the 0.4m3 digester. Feeding was done five days per week at 0.01m3 the first day, and on subsequent days the introduced volume corresponds to 1/60 of the useful volume (0.32m3), i.e., 0.0053m3 or 5 liters of substrate mixture depending on OM (%). It is calculated as follows:

$$OL = \frac{(Q \times OM) \times 5/7}{Vu} \qquad (12)$$

Organic Carbon Content

The organic carbon content of the sample was determined based on the organic matter content according to standard NF44-161. Organic carbon in waste can be estimated from the formula :

$$\mathrm{OC}(\%) = \frac{\mathrm{OM}(\%)}{1.724} \qquad (13)$$

Total Nitrogen Content

To determine the nitrogen content of our samples, we used the Kjeldahl method. Essentially, the analysis consists of the following steps: mineralization of the sample with sulfuric acid; titration of the distillate and calculation of the results (Abdoli et al.):

$$\%Total\ Nitrogen\ = \frac{100 \times (Va - Vb) \times NA \times 0.01401}{W \times 10} \qquad (14)$$

Where: Va = volume in ml of standard acid used in titration; Vb = volume in ml of standard acid used in blank; NA = normality of acid (HCl); W = weight in grams of sample.

3. Results and Discussion

3.1. Biogas sizing and production resuls

We obtained a volumetric flow rate Q = 10.6 liters/day. This means our digester was fed with 10 liters of substrate on the first day of fermentation. We used a ratio of 70:30 (food waste: cow dung) and a mixing ratio of 1:1:2 (waste: dung: water). The 70:30 ratio is a common strategy to optimize biogas production by combining carbon-rich substrates (green waste: 70) with nitrogen-rich substrates (cow dung: 30) . After 15 days of fermentation, daily feeding represented 1/60 of the useful volume of the digester, i.e., 5.3 liters . Recirculation of 10% of the digestate helped stabilize pH and introduce beneficial microorganisms for digestion (legesse et al., 2024). The biogas volume obtained is Vb = 57.6 liters/day. This means our digester produced about 57.6 liters of biogas at the start of fermentation, then increased progressively with daily feeding.The difference in drum levels in our system was designed to obtain sufficient pressure in the digester for storage and use of the produced gas. This resembles the design reported in reference with five metallic drums. We observed that continuous operation of the system was successful, as production was steady and the gas quantity was sufficient for use. However, system performance was average because the gas quantity was relatively low. This may be due to oxygen entering during daily recharging and the absence of a biogas pump to increase pressure, given budget constraints. During trials, we noticed that flow rate was difficult to regulate, mainly determined by pressure inside the inner tubes. When the inner tube emptied, gas flow weakened, posing problems when cooking required a strong flame.

Table 1. Parameters for Digester Sizing

Parameters	Value
Total digester	V_t = 0.4 m^3 (400 l)
Useful digester volume	V_u = 0.32 m^3 (320 l)
Hydraulic retention time	TRH = 30 days
Substrate mixture flow rate	Q = 10 l/day
Water volume	V_e = 10 l
Reused digestate volume	V_d = 0.032 m^3
Maximum gas volume	V_b = 1.20 m^3/day

This issue must be addressed in future storage system designs to ensure constant gas outlet pressure. In our experiment, we obtained initially 1.5 kPa, later 2.5–3 kPa. Literature indicates that outlet pressure for proper biogas stove operation must be at least 30 mbar (Castro et al., 2017).

3.2 Feedstock characterisation and digestion start-up performance

The physico-chemical characterisation of the selected substrates are presented in table 2. The mixed vegetable waste used as primary feedstock exhibited high moisture content and significant biodegradable organic matter fractions, confirming its appropriateness for wet anaerobic digestion systems. Such characteristics favour microbial accessibility and enhance hydrolysis efficiency, which constitutes the first and often rate-limiting stage of anaerobic digestion. The addition of fresh cow dung as inoculum contributed not only active methanogenic microorganisms but also improved nutrient balance within the digestion medium, particularly by optimising the carbon-to-nitrogen ratio.

Table 2. Characteristics of plant waste and cow dung

Material	Physicochemical parameters (%)				
	Dry matter	Hydrogen	Organic matter %	Organic Carbon	Nitrogen
Cow manure	91,19	8.81	7.21	4.18	0.42
Green waste	12,91	87.09	7	4.06	0.2
Fish waste	23,79	76.21	4.98	2.89	0.67

The digestion process exhibited a typical biological start-up phase. During the initial days following digester loading, no visible gas accumulation was observed, reflecting the lag phase associated with microbial acclimatisation and hydrolytic activity. Biogas production became noticeable from approximately the 10th day of digestion, as evidenced by the progressive inflation of the gas storage chamber. This delay corresponds to the time required for acidogenic and acetogenic microbial populations to establish favourable conditions for methanogenic archaea development. The observed start-up dynamics are consistent with conventional batch anaerobic digestion behaviour reported for organic waste and manure co-digestion systems operating under mesophilic conditions. The progressive increase in gas accumulation after the onset phase indicates effective substrate conversion and stable microbial activity within the digester.

3.3 Monitoring of operational parameters

Temperature evolution and process stability

Temperature monitoring throughout the digestion period revealed relatively stable thermal conditions within the reactor. The digester operated under ambient environmental conditions characteristic of the Sahelian climatic context, which generally favours mesophilic anaerobic digestion. The recorded temperature range remained compatible with microbial activity required for methane production. Such temperature stability is essential because anaerobic digestion efficiency is strongly temperature-dependent, with mesophilic conditions (typically 25–40 °C) promoting balanced microbial consortia and stable biogas yields (Weiland, 2010). No abrupt thermal fluctuations were observed during the experimental period, suggesting favourable insulation and heat retention within the metallic drum reactor. Stable temperatures contributed to the progressive establishment of methanogenic microorganisms, particularly after the initial acclimatisation phase. Similar findings have been reported in small-scale digesters operating under tropical climates, where ambient heat significantly reduces the need for external temperature regulation (Bond & Templeton, 2011). The experiment took place from January to February. The device was placed in an uncovered location to benefit from the full temperature range. The average temperature in Ndjamena during this period is approximately 26.8°C to 35.4°C. Biogas production from this

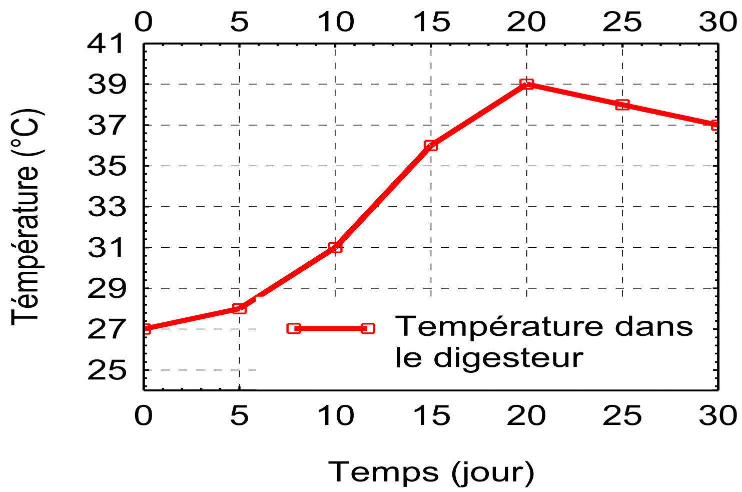

Figure 5. Température variation

system took place in two phases. The first phase was characterised by irregular biogas production, followed by a stable equilibrium phase. In order to maintain the progress of methanisation, we monitored the temperature change inside the digester, as shown in Figure 5:

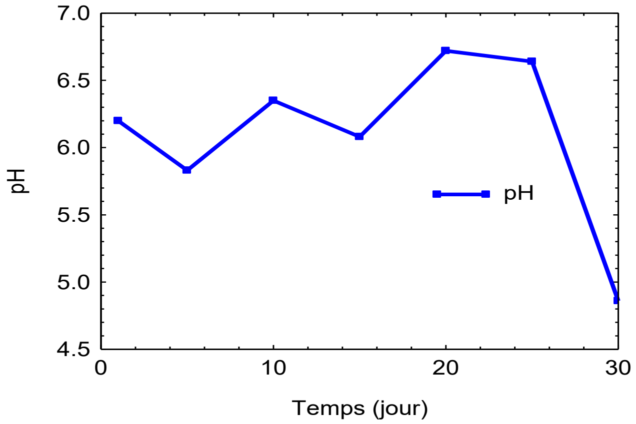

Figure 6. pH variation

pH evolution and digestion performance

The evolution of pH during the digestion process indicated conditions suitable for anaerobic microbial activity. Initial digestion stages are typically characterised by acidification due to hydrolysis and acidogenesis, followed by gradual stabilisation as methanogenesis develops. In this study, periodic pH measurements showed values remaining within a range compatible with methane-forming microorganisms. Methanogenic archaea are known to operate optimally within a pH range of 6.5–8.0; deviations beyond this interval may inhibit gas production (Mata-Alvarez et al., 2014). The observed pH stability suggests effective buffering capacity within the digestion medium, partly attributed to the addition of cow dung inoculum. Animal manure provides alkalinity and essential nutrients that mitigate acid accumulation and support microbial equilibrium. The combined stability of temperature and pH throughout the 30-day retention period confirms that the digestion process operated under favourable biochemical conditions, enabling progressive biogas generation and overall system stability.

3.4 Biogas production performance

Biogas production from the pilot anaerobic digester followed a progressive evolution pattern characteristic of batch digestion processes. During the initial days after substrate loading, no visible gas accumulation was observed, corresponding to the microbial acclimatisation and hydrolysis phase. Noticeable biogas production began around the tenth day of digestion, as indicated by the gradual inflation of the rubber inner tube used for gas storage. This onset period is consistent with the time required for acidogenic and acetogenic bacteria to create favourable conditions for methanogenic archaea activity (Weiland, 2010). Gas production increased steadily after the start-up phase, reflecting effective substrate biodegradation and stable microbial metabolism within the reactor. Th e use of mixed vegetable waste combined with cow dung inoculum likely enhanced microbial diversity and improved methane generation efficiency, as co-digestion systems are known to optimise nutrient balance and buffering capacity (Mata-Alvarez et al., 2014). Biogas storage was achieved through a flexible rubber gasometer connected to the digester outlet. The progressive expansion of the chamber provided a qualitative indicator of cumulative gas production. Although volumetric quantification was not performed due to the absence of calibrated gas flow measurement devices, pressure build-up and storage inflation confirmed continuous gas generation. Combustion tests were conducted to evaluate the energetic quality of the produced biogas. Ignition trials using the stored gas produced a stable blue flame, indicating a methane-rich combustible mixture. The appearance of a blue flame is widely recognised as evidence of adequate methane concentration and successful anaerobic digestion performance (Bond & Templeton, 2011). These

Figure 7. Measuring biogas volume using an air chamber

results confirm the technical feasibility of domestic biogas production using locally available organic waste under simplified operational conditions.

3.4 Technical feasibility and domestic applicability

The experimental results demonstrated the technical feasibility of domestic biogas production using locally available organic waste under simplified operating conditions. Although direct volumetric gas measurement was not performed using calibrated flow meters, biogas yield was estimated indirectly based on storage chamber expansion, gas pressure observations and digestion duration. The cumulative gas production observed over the 30-day retention period indicated sufficient output to sustain basic household cooking activities. Energy equivalence analysis was conducted to assess the practical usefulness of the produced biogas for domestic applications. Based on standard biogas calorific values reported in the literature (approximately 20–23 $MJ \cdot m^{-3}$), the estimated gas volume generated during digestion was considered adequate to partially substitute conventional cooking fuels such as firewood or charcoal (Bond & Templeton, 2011; Weiland, 2010). This substitution potential is particularly significant in the Chadian context, where households rely heavily on biomass fuels for daily cooking needs. From a technical standpoint, the digester operated without major operational failures throughout the experimental period, demonstrating structural integrity, gas tightness and functional substrate displacement between chambers. The use of locally available construction materials further enhances the system's affordability and replicability. Overall, the results confirm that small-scale anaerobic digestion represents a viable domestic waste-to-energy solution capable of contributing to energy access, waste management improvement and reduction of pressure on forest resources under similar socio-economic conditions. From estimation of reduced consumption of butane gas, firewood and charcoal, the biogas can reduce daily consumption by approximately 0,2 m^3 of butane, 1,24 kg of charcoal, and 2,5 kg of firewood (Gylain et al., 2023).

4. Conclusion

This study provided an experimental assessment of domestic biogas production from organic waste through anaerobic digestion under local conditions in Chad. The results confirmed the technical feasibility of converting household vegetable residues co-digested with cow dung into a combustible biogas suitable for domestic energy applications. The digestion process exhibited stable operational behaviour, with temperature and pH remaining within favourable ranges for methanogenic activity. Biogas production became noticeable after the initial microbial acclimatisation phase and increased progressively throughout the retention period. Combustion tests further validated the energetic quality of the produced gas through the observation of a stable blue flame.

This study demonstrated the technical and economic feasibility of anaerobic co-digestion of vegetable waste and cow dung in a small-scale portable digester under mesophilic conditions. Key findings include: (1) A digester of 0.4 m^3 capacity, operated in continuous mode, produced a maximum of 1.2 m^3/day of biogas. The system reduced household dependence on conventional fuels, saving up to 0.2 m^3 of butane, 1.24 kg of charcoal, and 2.5 kg of firewood per day; (2) Physico-chemical characterization confirmed that the substrates used (cow dung, vegetable waste, and fish waste) are suitable for anaerobic digestion, with C/N ratios adjusted to the optimal range (20–30). (3)The digestate produced had a pH of 6.9, making it a valuable organic fertilizer for agriculture. (4) The economic analysis showed a payback period of less than one year, with profitability higher when substituting charcoal compared to firewood. (5) Beyond energy production, the system demonstrated significant environmental relevance by offering a sustainable pathway for organic waste management while contributing to the reduction of fuelwood consumption and associated deforestation pressures. However, the study presents certain limitations, particularly the absence of precise volumetric gas quantification and detailed gas composition analysis due to limited instrumentation. Future research should therefore focus on integrating calibrated gas measurement systems, methane content analysis and long-term operational monitoring. (6) From a technological perspective, optimisation of digester insulation, agitation mechanisms and substrate pre-treatment could further enhance biogas yields. Scaling up household digesters into community-level systems also represents a promising pathway for expanding waste-to-energy deployment in Chad and similar developing-country contexts.

Based on the results obtained, the following recommendations are proposed: (1) Optimization of Gas Pressure: Future research should focus on improving gas storage and outlet pressure regulation. The current system produced pressures of 2.5–3 kPa, below the recommended 30 mbar for efficient stove operation. (2) Improved Storage Systems: (3) Development of low-cost, durable storage solutions (e.g., reinforced gas bags or small pressurized tanks) would enhance usability and safety. (4) Scaling Up the System: (5) Larger digester volumes could be tested to meet the needs of bigger households or community kitchens, while maintaining economic viability. (6) Alternative Inocula: In urban areas where cow dung is not easily available, fish waste and other organic residues should be further studied as potential inocula. (7) Policy Support: Government and local authorities should encourage adoption of biodigesters through subsidies, training programs, and awareness campaigns to reduce reliance on firewood and charcoal. (8) Integration with Agriculture: The digestate should be promoted as an organic fertilizer to improve soil fertility, reduce chemical fertilizer use, and provide farmers with an additional source of income.

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