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PERFORMANCE OF COW DUNG-DERIVED BIOGAS AS A SUSTAINABLE COOKING FUEL

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ABSTRACT
The rising demand for sustainable energy solutions has accelerated the search for low-cost, renewable, and eco-friendly cooking fuels. This study evaluated the performance of biogas derived from cow dung as a potential domestic energy source using a laboratory-scale batch anaerobic digestion system. Fresh cow dung was homogenized with water at a ratio of 4.5:20 (w/v) and introduced into a 25-liter high-density polyethylene (HDPE) digester fitted with inlet and outlet valves and linked to a gas storage unit. The system operated under mesophilic conditions for eight days, during which ambient temperature and daily gas yield were monitored. Biogas generation was negligible during the initial three days (0.00–0.018 kg), representing a lag phase in microbial activity. From Day 4 onward, production increased steadily, peaking at 9.09 kg on Day 8. Regression analysis demonstrated a strong positive correlation between retention time and biogas yield ($R^2 = 0.94$, $p < 0.001$), whereas temperature exhibited no significant influence ($r = –0.08$, $p = 0.86$). These results indicate that cow dung serves as a reliable substrate, capable of sustaining biogas production even under natural temperature variations. The findings confirm the viability of cow dung-derived biogas as a sustainable cooking fuel, particularly for rural households. Adoption of this technology can reduce dependence on firewood and kerosene, mitigate environmental degradation, and improve household air quality. Moreover, the use of inexpensive, locally available materials for digester construction highlights its practicality for widespread application in resource-limited communities.

Keywords: Anaerobic digestion, Biogas production, Cow dung, Renewable cooking fuel, Sustainable energy

INTRODUCTION
The global pursuit of sustainable energy has accelerated the demand for renewable alternatives to conventional cooking fuels. Among these, biogas derived from cow dung has emerged as a viable solution, offering the dual benefits of organic waste management and clean energy generation (Surendra *et al*., 2020). With approximately 2.6 billion people still dependent on traditional biomass for cooking contributing to indoor air pollution, deforestation, and greenhouse gas emissions cow dung-based biogas presents a promising pathway for mitigating both environmental degradation and public health risks (WHO, 2022).
Cow dung, a byproduct of livestock farming, is often considered a waste or environmental nuisance (Njogu *et al*., 2022). However, recent advances in anaerobic digestion technology have redefined its utility as a renewable energy source (Rilwanu *et al*., 2025). Through anaerobic microbial processes, cow dung is converted into biogas a combustible mixture primarily composed of methane (50–75%) and carbon dioxide (25–50%) while also producing nutrient-rich digestate usable as organic fertilizer (Kumar *et al*., 2024). Studies suggest that cow dung-derived biogas can reduce greenhouse gas emissions by up to 80% compared to firewood and deliver a consistent, efficient cooking fuel with methane content as high as 70% (Mittal *et al*., 2018).
The combustion of solid fuels and kerosene contributes significantly to global warming by releasing methane (CH_4), a potent greenhouse gas that traps 86 times more heat than CO_2 over a 20-year period. In 2020, cooking-related emissions reached 1.69 gigatons of CO_2 equivalent accounting for 3% of total global GHG emissions and 56% of emissions from buildings with 77% of these emissions originating from non-renewable biomass (Moses *et al*., 2022). Widespread dependence on wood and charcoal for cooking fuels drives unsustainable harvesting, leading to deforestation, land degradation, and biodiversity loss (FAO, 2018; IEA, 2023). Achieving universal access to clean cooking by 2030 could avoid up to 1.5 Gt CO_2e in emissions, particularly in Sub-Saharan Africa (IEA, 2023). Biogas technology offers an effective mitigation pathway by capturing methane from organic waste and displacing biomass use, thereby delivering both climate and health co-benefits (World Bank, 2023). Clean cooking should thus be prioritized in climate finance agendas due to its environmental, health, and socio-economic advantages (Saleh & Sillah, 2022).
Household air pollution (HAP) resulting from incomplete combustion of traditional fuels is linked to 3.2–3.7 million premature deaths annually (WHO, 2022). These include fatalities from acute respiratory infections, COPD, stroke, ischaemic heart disease, and lung cancer. In addition, accidental kerosene ingestion and fire-related injuries are prevalent in low- and middle-income countries due to unsafe household energy practices (WHO, 2022; UNICEF, 2021).
Policy interest in cow dung biogas is gaining traction globally. In northern India, the Gram Urja initiative in Uttar Pradesh aims to cut LPG dependency by 70%, enhance rural income, and promote fertilizer recovery from cattle waste (Business Standard, 2025). In East Africa, Kenya's biogas program has deployed over 17,000 digesters, saving 4 tons CO_2eq, per household annually, reducing firewood use, and improving soil fertility (Circle Economy, 2021). Similarly, smallholder farmers in Tanzania report multiple benefits, including reduced cooking time, lower fuel costs, and better respiratory health outcomes (FAO, 2025).
Life cycle assessments in India have shown that co-digesting cow dung with agricultural residues can reduce climate impacts by 13%, improve resource efficiency by 60%, and decrease health risks by 48% (Surendra *et al*., 2020). In Indonesia, village-scale biogas systems have helped reduce LPG consumption and GHG emissions, contributing to national savings on fuel and fertilizer subsidies (IEA, 2023).
As population growth drives energy demand, particularly in developing regions, the reliance on biomass for cooking

remains high contributing to deforestation and worsening climate change (IEA, 2024; FAO, 2023). Industrial cooking gas has also become increasingly unaffordable, especially for rural households (Jeremiah, 2025). Meeting Net Zero targets by 2050 will require expanding clean cooking access to 300 million people annually, with biogas expected to contribute 10% of new connections by 2030 (IEA, 2023).

Given its accessibility, simplicity of production, and dual role in waste treatment and clean energy supply, cow dung biogas stands out as a sustainable solution for household energy. Therefore, this study evaluates the performance and viability of cow dung-derived biogas as a clean, efficient, and climate-friendly cooking fuel.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Damaturu, the capital city of Yobe State, located in the northeastern region of Nigeria (Figure 1). Geographically, Damaturu lies between latitude 11°44′N and longitude 11°58′E, with an average elevation of about 430 meters above sea level. The state capital is home to 88,014 people and has a land area of 2,366 square kilometres (NPC, 2006).

Damaturu Local Government Area (LGA) is bordered on the North by Tarmuwa (LGA), on the South by Gujba (LGA), on the West by Fune (LGA) and on the East by Kaga (LGA) in Borno State. The area falls within the Sudano-Sahelian climatic zone, characterized by long dry seasons (spanning from October to May) and short wet seasons (typically from June to September), with an average annual rainfall of 500–1000 mm. Average temperatures range from 25°C to 40°C, making the environment favourable for microbial activities necessary for anaerobic digestion.

Damaturu is predominantly an agrarian and livestock-rearing community, with cattle, sheep, and goats widely kept by the rural population. The abundance of cattle dung in the area makes it a strategic location for exploring the potential of biogas production from organic waste. Most households in both urban and rural settlements of Damaturu rely heavily on firewood, charcoal, and kerosene as primary sources of cooking energy, leading to deforestation and exposure to indoor air pollution. Given the growing energy demand, environmental concerns, and availability of raw materials, Damaturu presents a suitable setting for investigating the performance and sustainability of cow dung-derived biogas as an alternative cooking fuel.

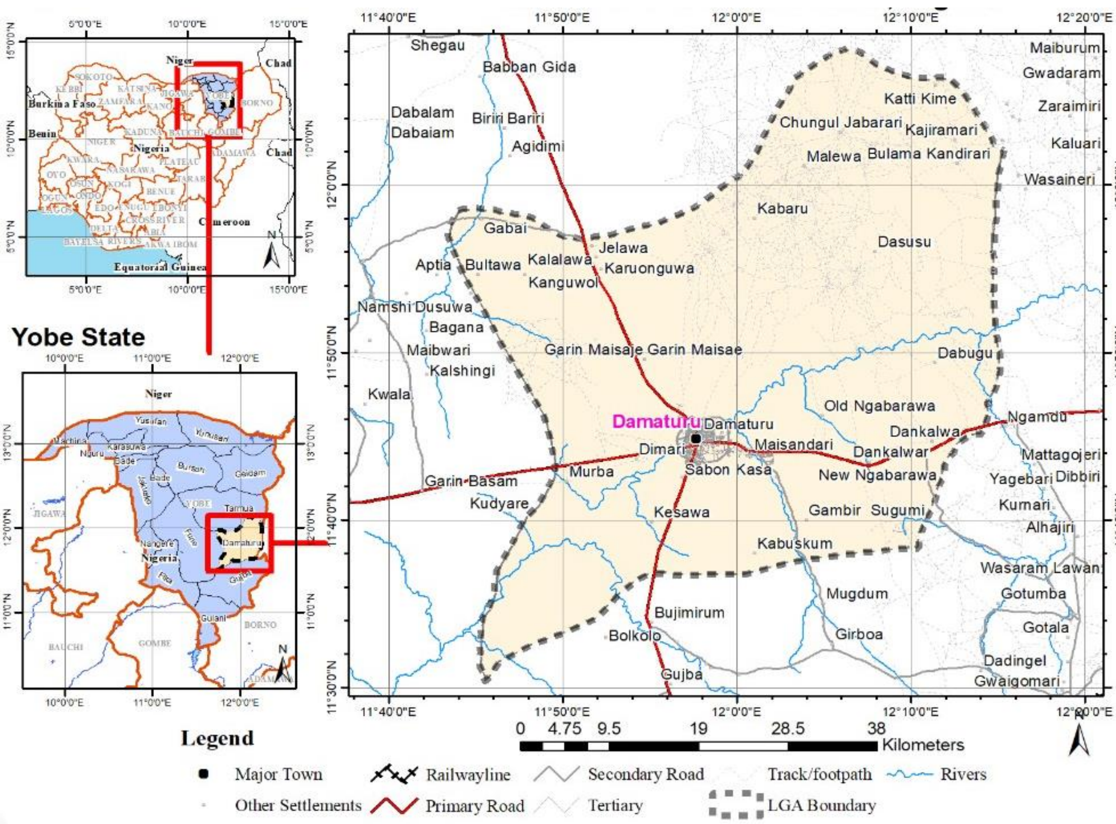

Figure 1: Map of Yobe State Showing Damaturu town (Gana and Sa'id, 2022)

Sample Collection

"Fresh cow dung was collected within 30 minutes of excretion from a cattle grazing site in Kasaisa Village, along Gujba Road, Damaturu, Yobe State, Nigeria. Only uncontaminated samples were taken using clean, non-metallic tools, sealed in sterile airtight containers, and transported to the laboratory within one hour. This procedure preserved microbial activity, minimized compositional changes, and aligned with standard protocols for anaerobic digestion research (Njogu *et al*., 2022; Abubakar & Ismail, 2012)."

Slurry Preparation

The experiment was conducted in the Biology Laboratory of Yobe State University, Damaturu. A portion of the collected cow dung (4.2 kg) was mixed with 5 liters of clean tap water, following a slurry ratio of approximately 1:1.2 (w/v), based on the method of Mattocks *et al*. (1984). Water was added gradually while stirring with paddle until a smooth and uniform mixture was achieved. Homogeneity of the slurry is essential for consistent microbial action during anaerobic digestion.

Construction of the Bio-digester

A low-cost, batch-type anaerobic digester with a 25-liter capacity was constructed using locally available materials. The system was designed to operate under mesophilic conditions (25°C–40°C), optimal for microbial activity and methane generation (Eze *et al*., 2011). The components of the bio-digester (Figure 2) were as follows:

i. Digester chamber: 25-liter HDPE plastic container
ii. Inlet pipe: 1.5-inch PVC pipe for feeding slurry
iii. Outlet pipe: PVC pipe at the lower side for digestate removal, installed at a 45° angle to facilitate flow
iv. Gas outlet hose: Rubber tubing connected to the digester's headspace
v. Gas storage unit: Used vehicle tire inner tube
vi. Non-return valve: To prevent gas or air backflow
vii. Sealing materials: Rubber gaskets and waterproof adhesives to ensure airtight assembly

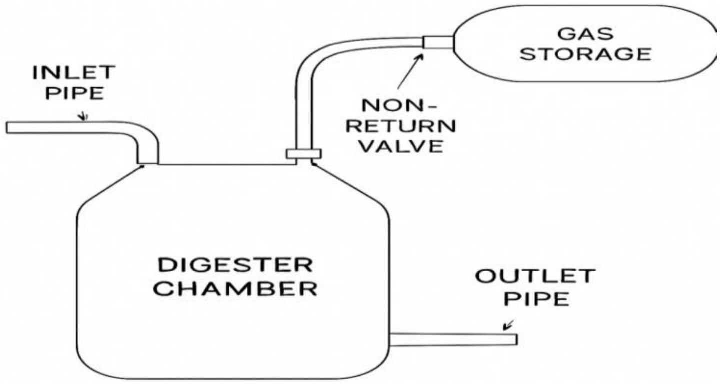

Figure 2: Schematic Diagram of a Low-Cost Batch-Type Anaerobic Bio-digester for Cow Dung-Based Biogas Production

Digester Assembly and Operation

The plastic container was modified by creating holes for inlet, outlet, and gas outlet fittings. These were sealed to prevent leaks. The digester was filled to 70% of its volume with the prepared slurry, leaving 30% as headspace for biogas accumulation. The system was sealed to establish anaerobic conditions.

The generated gas flowed through the outlet hose into the storage tube. As pressure built up, the gas displaced digestate through the outlet pipe, simulating agitation without mechanical stirrers. The biogas, primarily consisting of methane (CH_4) and carbon dioxide (CO_2), was stored for later use as a cooking fuel.

A second digester setup, using an insulated 25-liter HDPE container, was also prepared. This setup was identical in design but included additional insulation (thermal sheet) to stabilize internal temperature. Joints were sealed using waterproof adhesive and rubber gaskets (Itodo *et al*., 2007). The slurry in this setup was prepared with 4.5 kg of cow dung and 20 liters of water (1:4.5 w/v), using 50% tap water. The slurry was stirred until uniform, and the digester was filled to 70% capacity. The 30% headspace allowed biogas accumulation.

Digestion Conditions and Gas Measurement

The experiment was conducted under ambient laboratory conditions, with daily temperatures ranging from 28°C to 34°C. Temperature was measured using a laboratory-grade thermometer (Sawyer, 2003). Biogas yield was measured daily for 8 days using the water displacement method, where gas from the digester displaced water in an inverted graduated cylinder (Gashaw *et al.,* 2014).

Statistical Analysis

Descriptive statistics were used to summarize biogas production and ambient temperature over the 8-day period. A simple linear regression was conducted to assess the relationship between biogas yield and time (days), while a Pearson correlation was used to test the association between temperature and gas production. Regression analysis and Pearson correlation were performed at 5% level of probability

RESULTS AND DISCUSSION

The cumulative biogas yield from cow dung over an 8-day anaerobic digestion period is presented in Table 1. Gas production was negligible during the first three days, averaging less than 0.01 kg/day. However, from Day 4 onward, a sharp increase was observed, reaching a peak of 9.09 kg on Day 8. The total gas yield over the 8-day period was 30.31 kg, with over 95% of that produced from Day 4 to Day 8.

Table 1: Daily Environmental Temperature and Biogas Production

Day	Ambient Temperature (°C)	Biogas Produced (kg)
1	39	0.000
2	38	0.002
3	40	0.018
4	43	2.800
5	45	3.700
6	40	6.500
7	37	8.200
8	40	9.090

The daily trend of biogas production from cow dung over 8-day anaerobic digestion period is presented in Figure 3. The graph shows a clear upward trend in biogas production over the 8-day period, with minimal output in the first three days, followed by a sharp and steady increase from Day 4 to Day 8. The dashed line represents the linear regression trend, confirming a statistically significant rise in gas yield (R^2 = 0.94, $p < 0.001$). This pattern reflects the typical phases of microbial growth during anaerobic digestion starting with a lag phase and progressing into active methanogenesis.

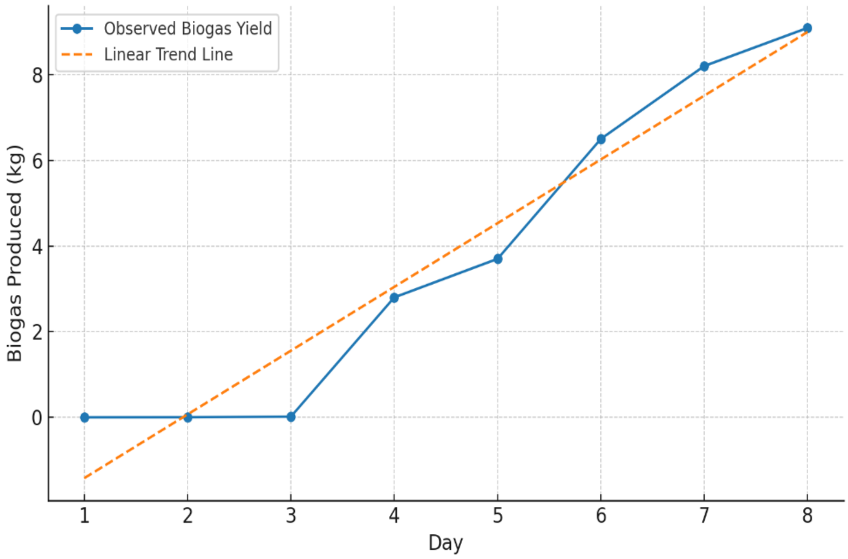

Figure 3: Daily Trend of Biogas Production from Cow Dung over 8-Day Anaerobic Digestion Period

Table 2: Statistical Summary of Biogas Production Trends

Statistical Test	Test Statistic	P-Value	Interpretation
Linear Regression (Biogas vs. Day)	Slope = 1.49, R^2 = 0.94	0.00007	Strong positive trend, statistically significant
Pearson Correlation (Biogas vs. Temperature)	r = -0.08	0.86	No significant correlation

Table 2 presents the statistical relationships between biogas yield, retention time, and ambient temperature. The linear regression analysis revealed a strong and statistically significant positive relationship between digestion time and biogas production (slope = 1.49, R^2 = 0.94, $p < 0.001$). This indicates that 94% of the variation in biogas yield was explained by retention time, confirming that gas production increased progressively with longer digestion periods. Conversely, the Pearson correlation between biogas yield and temperature (r = –0.08, p = 0.86) was weak and not statistically significant. This suggests that within the mesophilic temperature range experienced during the study (37–45 °C), fluctuations in ambient temperature did not exert a meaningful influence on biogas output. These results emphasize that retention time was the key determinant of gas yield, while temperature variability under natural conditions had negligible effect on production efficiency.

Discussions

The trend in biogas yield indicates a typical microbial growth curve during anaerobic digestion. The initial lag phase (Days 1–3), where gas production remained minimal (0.000–0.018 kg), could be attributed to the time required for methanogenic bacteria to adapt to the anaerobic environment. This phase is well-documented by Nopharatana *et al*. (2007) and Ukpai (2012), who also observed slow gas evolution at the beginning of digestion due to microbial acclimatization and substrate hydrolysis delay.

From Day 4 onwards, the system entered the log/exponential phase, marked by a rapid increase in gas output from 2.8 kg to 9.09 kg within four days. This sharp rise corresponds to the active growth and metabolism of methanogens, which efficiently converts volatile fatty acids (VFAs) and intermediates into methane and carbon dioxide. These findings align with the observations of Sadaka (2000), who recorded peak production during similar mid-phase time frames in cow manure digestion.

The observed biogas production pattern is consistent with the microbial growth phases described in earlier studies. The initial low production phase mirrors the findings of Abubakar and Ismail (2012), who attributed the lag to the presence of complex organic compounds and carbon source shifts, which require enzymatic breakdown before methanogenesis can commence.

Similar to this study, Tyagi (2010) also reported delayed gas onset when cow dung was used as a mono-substrate. However, unlike findings by Rabah *et al*. (2008), which reported a decline in gas yield after the second week due to possible substrate exhaustion or process inhibition, the present study recorded a steady increase throughout the duration. This discrepancy could be due to differences in cattle feed, microbial strains, or digester design.

Although pH was not actively controlled during this experiment, the consistent rise in gas output could be an indication that the digestion process remained within optimal operational parameters. Literature suggests that cow dung has natural buffering capacity, which helps maintain a stable pH range favorable to methanogenic activity (Chen *et al*., 2008). Furthermore, while gas composition was not analyzed in this study, previous studies indicate that biogas from cow dung typically contains between 47% and 70% methane (Mittal *et al*., 2018), making it highly suitable for cooking applications. The linear regression analysis further confirms this trend statistically, with a slope of 1.49 kg/day and an R^2 value of

0.94, indicating that 94% of the variation in biogas production was explained by time. The associated p-value (<0.001) confirms that the increase in biogas yield over the 8 days was highly significant. Conversely, the Pearson correlation between temperature and gas volume was weak and not statistically significant ($r = -0.08$, $p = 0.86$). Despite fluctuations in ambient temperature between 37°C and 45°C, gas output remained largely unaffected. This suggests that cow dung digestion, under mesophilic conditions, is resilient to minor environmental variations a finding consistent with field-based studies in tropical climates (Surendra *et al.*, 2020; Ukpai, 2012).

While ambient temperatures ranged from 37°C to 45°C, well within the mesophilic range (25–45°C) optimal for anaerobic digestion, no significant correlation was found between temperature and gas output ($r = -0.08$, $p = 0.86$). This suggests that temperature variation within this range did not influence biogas yield, likely due to the thermostability and resilience of mesophilic microbial consortia. This contrasts the findings from Chen *et al*. (2008), where temperature fluctuations outside the mesophilic range led to process inhibition. However, it confirms the robustness of cow dung digestion under natural environmental conditions, reinforcing similar conclusions from Surendra *et al*. (2020) and Eze *et al*. (2011), who highlighted cow dung's adaptability in variable tropical climates.

The result implies a balanced digestion process, potentially with methane content averaging around 47–70% based on literature estimates (Mittal *et al.,* 2018), although direct gas composition analysis was not performed in this study.

CONCLUSION

This study evaluated the performance of cow dung-derived biogas as a sustainable cooking fuel using a laboratory-scale, batch type anaerobic digester under ambient environmental conditions in Damaturu, Nigeria. The results demonstrated a clear and statistically significant increase in biogas production over the 8-day digestion period, with a cumulative yield of 30.31 kg. Peak biogas generation occurred between Days 6 and 8, confirming that cow dung is a suitable and efficient substrate for biogas production in mesophilic environments.

Linear regression analysis confirmed a strong positive relationship between biogas production and time ($R^2 = 0.94$, $p < 0.001$), while no significant correlation was observed between biogas volume and ambient temperature ($r = –0.08$, $p = 0.86$), indicating that minor fluctuations within the mesophilic range did not affect microbial performance. These findings support the viability of deploying low-cost biogas digesters in rural communities without temperature regulation systems. The digester setup, fabricated from locally sourced materials, proved to be cost-effective, efficient, and suitable for household-scale biogas generation. This reinforces the potential of biogas as a reliable, renewable energy alternative that can reduce dependence on firewood, mitigate deforestation, and improve household air quality.

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