A Preliminary Evaluation of Biogas Generation from Cattle Manure at Caño Fistola Farm of the Colombian Caribbean

Una evaluación preliminar de la generación de biogás a partir de estiércol de ganado en la finca Caño Fistola del Caribe colombiano

Uma avaliação preliminar da geração de biogás a partir de esterco de gado na fazenda Caño Fistola, no Caribe colombiano

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Abstract

This work evaluated the potential for biogas production from cattle manure on a rural property located in Ponedera, Atlantic, Colombia. Initially, the materials needed to build the biodigester and the quantities of substrate required for the experiment were defined. Once the biodigester was built, the experiment was implemented and biogas measurements were carried out 10 days after filling the biodigester for 20 days. An estimate of the theoretical and experimental production of biogas was carried out, considering different parameters and methodologies. The results indicated that the biogas production potential of the Caño Fistola farm (which has 150 heads of cattle) was 3,685 m³ per year, equivalent to 17,319.5 kWh of energy per year and 1,695.1 kg of LPG. To cover the farm's minimum consumption (approximately 200 kWh per month, 2,400 kWh per year), only 3 biodigesters and 23 heads of cattle would be needed. These results highlight the potential of implementing low-cost anaerobic biodigesters to obtain biogas and achieve energy self-sufficiency on rural properties. In a global context, this study highlights the importance of seeking sustainable and energy-efficient solutions to face current challenges related to energy production and waste management. The production of biogas from cattle manure on rural properties not only has the potential to provide a renewable and clean energy source, but also contributes to reducing greenhouse gas emissions and mitigating climate change. This approach can promote energy self-sufficiency in rural areas, improve agricultural waste management and promote sustainable development in farming communities.

Keywords: rural area, energy self-sufficiency, organic waste, anaerobic digestion, biogas.

Resumen

Este trabajo evaluó el potencial de producción de biogás a partir de estiércol de ganado en una propiedad rural ubicada en Ponedera, Atlántico, Colombia. Inicialmente se definieron los materiales necesarios para construir el biodigestor y las cantidades de sustrato requeridas para el experimento. Una vez construido el biodigestor, se implementó el experimento y se realizaron mediciones de biogás 10 días después de llenar el biodigestor durante 20 días. Se realizó una estimación de la producción teórica y experimental de biogás, considerando diferentes parámetros y metodologías. Los resultados indicaron que el potencial de producción de biogás de la finca Caño Fistola (que cuenta con 150 cabezas de ganado) fue de 3.685 m³ anuales, equivalente a 17.319,5 kWh de energía al año y 1.695,1 kg de GLP. Para cubrir el consumo mínimo de la finca (aproximadamente 200 kWh mensuales, 2.400 kWh anuales), sólo se necesitarían 3 biodigestores y 23 cabezas de ganado. Estos resultados resaltan el potencial de implementar biodigestores anaeróbicos de bajo costo para obtener biogás y lograr la autosuficiencia energética en propiedades rurales. En un contexto global, este estudio destaca la importancia de buscar soluciones sostenibles y energéticamente eficientes para afrontar los desafíos actuales relacionados con la producción de energía y la gestión de residuos. La producción de biogás a partir de estiércol de ganado en propiedades rurales no sólo tiene el potencial de proporcionar una fuente de energía limpia y renovable, sino que también contribuye a reducir las emisiones de gases de efecto invernadero y mitigar el cambio climático. Este enfoque puede promover la autosuficiencia energética en las zonas rurales, mejorar la gestión de residuos agrícolas y promover el desarrollo sostenible en las comunidades agrícolas.

Palabras clave: zona rural, autosuficiencia energética, residuos orgánicos, digestión anaeróbica, biogás.

Resumo

Este trabalho avaliou o potencial de produção de biogás a partir de esterco bovino em uma propriedade rural localizada em Ponedera, Atlântico, Colômbia. Inicialmente foram definidos os materiais necessários para a construção do biodigestor e as quantidades de substrato necessárias para o experimento. Uma vez construído o biodigestor, o experimento foi implementado e as medições de biogás foram realizadas 10 dias após o enchimento do biodigestor por 20 dias. Foi realizada uma estimativa da produção teórica e experimental de biogás, considerando diferentes parâmetros e metodologias. Os resultados indicaram que o potencial de produção de biogás da fazenda Caño Fistola (que possui 150 cabeças de gado) era de 3.685 m³ por ano, equivalente a 17.319,5 kWh de energia por ano e 1.695,1 kg de GLP. Para cobrir o consumo mínimo da fazenda (aproximadamente 200 kWh por mês, 2.400 kWh por ano), seriam necessários apenas 3 biodigestores e 23 cabeças de gado. Esses resultados ressaltam o potencial da implantação de biodigestores anaeróbios de baixo custo para obtenção de biogás e alcançar autossuficiência energética em propriedades rurais. Num contexto global, este estudo destaca a importância de procurar soluções sustentáveis e energeticamente eficientes para enfrentar os desafios atuais relacionados com a produção de energia e a gestão de resíduos. A produção de biogás a partir de esterco bovino em propriedades rurais não só tem potencial para fornecer uma fonte de energia renovável e limpa, mas também contribui para reduzir as emissões de gases de efeito estufa e mitigar as mudanças climáticas. Esta abordagem pode promover a auto-suficiência energética nas zonas rurais, melhorar a gestão dos resíduos agrícolas e promover o desenvolvimento sustentável nas comunidades agrícolas.

Palavras-chave: zona rural, autossuficiência energética, resíduos orgânicos, digestão anaeróbia, biogás.

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1. Introduction

Renewable energies, such as biogas derived from animal waste, present successful potential at the domestic and industrial level, with a positive impact on SDGs 7, 9, 12, and 13, which highlight innovation and climate action for the preservation of the environment. atmosphere. atmosphere. Given the decrease in fossil fuel reserves and their environmental effects, scientists are focusing on new processes and products, highlighting the growing attention towards the production of biofuels (Fernández et al., 2015).

Climate change constitutes one of the most urgent challenges of the 21st century, and its acceleration is mainly attributed to human actions that emit significant amounts of greenhouse gases (GHG) into the atmosphere (Smith et al., 2014; 2020). One of the relevant sources of these GHGs is livestock farming, specifically through the production and inadequate management of bovine manure, which generates methane, a gas with a significantly greater global warming power than carbon dioxide (Steinfeld et al., 2006; Hoyos et al., 2024).

On the other hand, the world faces exponential growth in energy demand. Conventional energy sources, based on fossil fuels, are not only limited but are also large GHG emitters (Jones and Kammen, 2011). Global oil demand is undergoing recent changes, and an increase in gas demand is expected. Meanwhile, the conflict between Russia and Ukraine has generated a crisis in global gas prices, highlighting the importance of alternative energy sources, where biomass emerges as a viable option (Hoyos et al., 2024).

According to the Energy Information Administration of the United States and the European Union, Biomass includes renewable organic materials from plants and animals, standing out as an expanding energy source. In developing countries, it plays a vital role in everyday activities such as cooking, heating, electricity generation, and transportation, significantly contributing to primary energy use (U.S. Energy Information Administration, 2022; Hoyos et al., 2024).

In 2021, biomass contributed nearly 5 trillion British thermal units, representing approximately 5% of total primary energy consumption in the United States. An increase in the generation of biowaste is projected until 2025, which can be sustainably transformed into various bioproducts for industrial, commercial, agricultural, and energy applications (Culaba et al., 2023).

The global biowaste-to-bioenergy technologies market has seen remarkable growth, reaching USD 116.5 billion in 2021, expected to reach USD 229 billion by 2030, maintaining a compound annual growth rate of 7.7 % (Hoyos et al., 2024).

In 2019, the global biomass supply was 56.9 EJ, of which 85% came from solid biomass sources. 655 TWh of electricity were generated from biomass, with 68% solid biomass, 17% municipal and industrial waste, and 13% biogas (World Bioenergy Association, Global Bioenergy Statistics 2021). These data highlight the current importance of biomass as an energy source.

Biogas technology is not without problems. The reviews have attempted to address research on the failure and low adoption of the technology, focusing mainly on aspects such as raw materials, economics, socioeconomics, incentives, types of digesters, perception of the technology by users, and political challenges (Tagne et al., 2021).

There are four generations of biomass, with third-generation biomass, such as algae, used to produce biodiesel, biogas, and bioethanol (Ishak et al., 2022). As for organic waste, such as animal manure, they are identified as valuable for the generation of energy and biofertilizers. However, excessive accumulation of manure in some regions can cause environmental problems, such as soil, water, and air pollution. Improper management of large quantities of manure generates significant GHG emissions, such as methane and nitrous oxide, with detrimental consequences for the environment and surrounding communities. To address these challenges, thermochemical and biochemical processes, such as gasification and anaerobic digestion, are proposed to valorize and stabilize these wastes (Meng et al., 2022; Yang et al, 2022).

Anaerobic digestion of raw materials, whether of animal or plant origin, constitutes an essential process for the supply of energy. This process is generally composed of four fundamental stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Various designs have been developed to take advantage of the biogas generated by the digestion of raw materials, both for domestic and industrial use (Black et al., 2021; Rasul et al., 2016). Critical factors, such as volatile solids content, biological (biochemical) oxygen demand, chemical oxygen demand, carbon-to-nitrogen (C/N) ratio, and the presence of compound inhibitors, must be carefully considered in raw materials during the digestion process. These parameters, along with others such as reactor design and operating conditions, directly impact the performance of anaerobic digestion processes (Tabatabaei, 2018).

In the Colombian context, livestock farming has emerged as a prominent sector in the agroindustry, with around 28 million heads of livestock. Although this sector contributes significantly to the Colombian economy and society, it generates waste that can become a potential source of pollution. The implementation of technologies such as anaerobic digestion of these wastes is presented as an alternative to promote recycling and energy generation (Resende et al., 2015; Martinez-Rubio, 2021; Hoyos et al., 2024).

In the department of Atlántico, there are around 224,978 heads of cattle, which generate 824,727 tons/year of manure (Velásquez et al., 2018). One of the main objectives for the establishment of biodigesters is that they represent a valuable option to adequately manage the waste produced on livestock farms, these in turn are usually implemented as the anaerobic medium used for the generation of methane gas, which can be used to satisfy the energy demands of rural communities (Díaz-Vázquez et al., 2020). According to FAO (2011), biogas is presented as a simple and viable technology to implement, mainly by rural communities.

In the municipality of Ponedera, there are 17,130 heads of cattle distributed in 266 agricultural production units (UPA), in which the activities of intensive livestock farming are carried out daily. There is no record of a farm that is responsible for generating biofuels from the manure produced by livestock species. There is a total lack of knowledge on the part of the owners regarding the environmental and energy benefits that the use of manure can bring, as a raw material in the implementation of anaerobic biodigesters (MADR, 2019).

The anaerobic digestion process from manure is characterized as the key to a more sustainable production system, due to the reduction in the use of conventional energy and commercial fertilizers, in addition to providing a highly efficient method to recycle resources and close the production cycle. The growing search for new alternative sources for energy production and waste recycling points to the use of animal waste as an economically viable option given the relevance of livestock farming in Colombia (Abbasi et al., 2012).

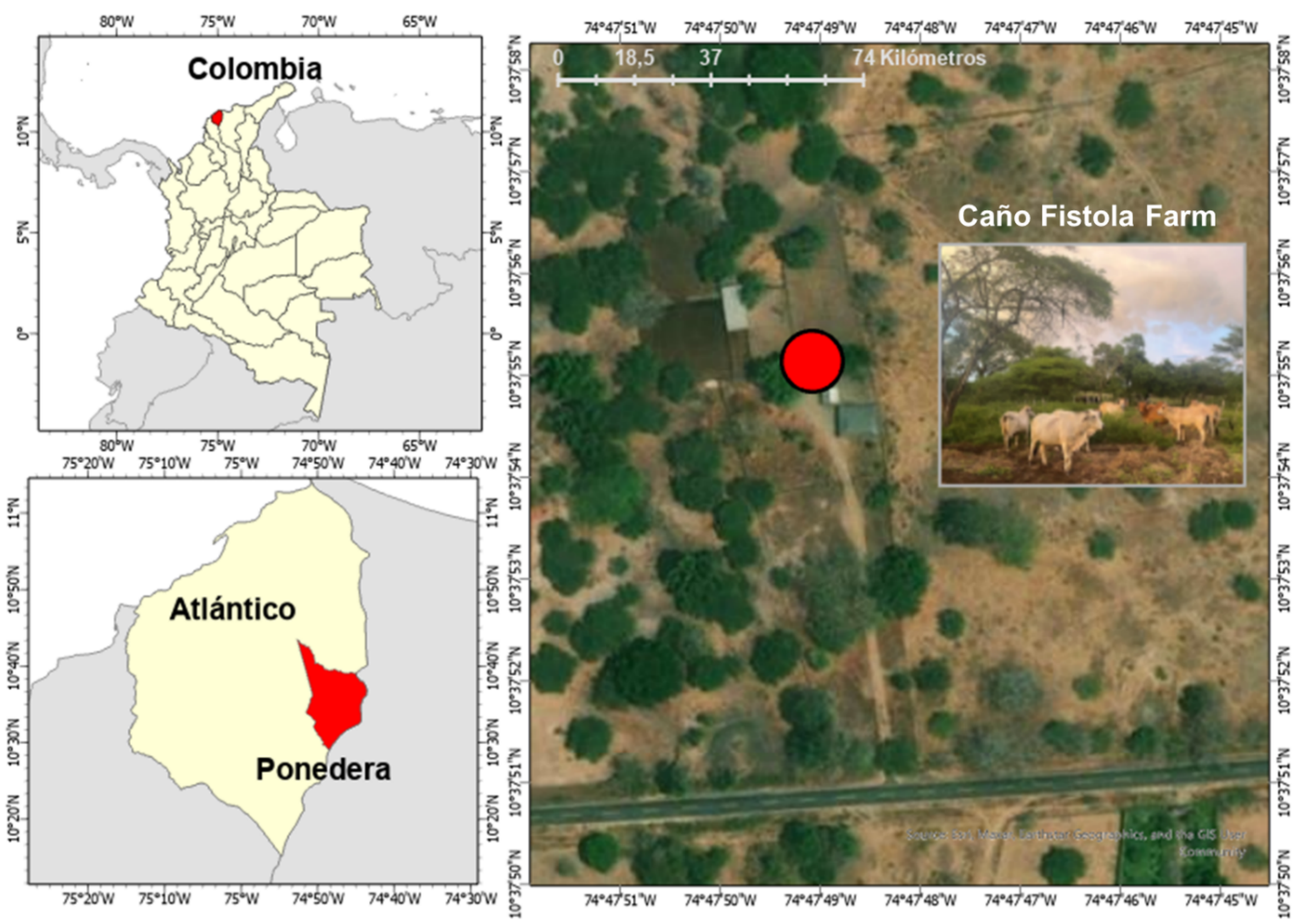
In places like the municipality of Ponedera, Atlántico, with a significant cattle population, the potential for biogas production can be considerable. However, to date, no specific methodology has been developed to estimate this potential in the region. In this line, the main objective of this work was to evaluate the potential for generating biogas produced by a homemade discontinuous anaerobic biodigester with bovine manure as a substrate. By demonstrating the feasibility and benefits of biogas production from bovine manure in rural areas, this study contributes to the broader vision of sustainable energy practices and environmental conservation efforts on a global scale. Furthermore, the insights gained from this research can inform policymakers and stakeholders in other regions about the potential of implementing similar biogas production initiatives to address energy needs while mitigating environmental impacts. Thus, the study's implications extend beyond the local context to offer valuable lessons and solutions applicable to diverse geographic settings worldwide.

2. Materials and methods

2.1 Study area

The anaerobic digestion system was installed on the Caño Fistola farm in the municipality of Ponedera, Atlántico, Colombia, located at 10.63182° N and 74.79696° W. The farmhouses have approximately 150 heads of cattle, with an average weight of 400 kg each (Figure 1).

Figure 1. Location of the study area.



According to the Food and Agriculture Organization of the United Nations (FAO, 2022), the Atlantic region is characterized by an average annual temperature of 28°C, with maximum temperatures reaching 35.5°C and minimum temperatures dropping to 22.2°C. °C. In the municipality of Ponedera, the average temperature is 27°C.

2.2 Estimation of biogas production potential

To estimate the biogas production of a biodigester, data related to the live weight of the animals and the daily confinement fraction were included. In addition, Equations 1, 2, and 3 were used to calculate the daily and annual waste production. Table 1 describes the values of the qualitative parameters used.

To calculate the daily production of cattle manure biodigester was used in Equation (1).

$$PDDB = \sum(N° * TC * PE) \qquad \text{Eq. (1)}$$

Where: PDDB: m^3_{manure} day^{-1} (daily production of cattle manure from the animal category); N°: absolute number (number of heads belonging to the animal category); TC: confinement time (hours of confinement per day); PE: m^3_{manure} $head^{-1}$ h^{-1} (specific production of bovine manure by category).

To calculate the daily biogas production biodigester was used in Equation (2).

$$PDB = N° \quad \text{Eq. (2)}$$

Where: PDB: $m^3\ day^{-1}$ (daily biogas production); N°: absolute number (number of animals); PM: kg (Middleweight); PE: kg (standard weight); FDC: dimensionless (daily fraction of confinement (between 0 and 1)); SV: $kg_{SV}\ head^{-1}\ year^{-1}$ (daily production of cattle manure from the animal category); FCM: dimensionless (methane conversion factor for system baseline). B_0: $m^3CH_4.kg_{SV}^{-1}$ (methane production capacity from manure); fb: dimensionless (uncertainty correction factor); CH_4: % (percentage of methane in biogas). The values used to estimate the biogas production potential are described in Table 1.

2.3 Construction of the anaerobic biodigester

2.3.1 Materials

The initial work process consisted of the construction of the biodigester. The materials used in the production of the biodigester were purchased at construction materials stores. Table 2 shows a list of the materials used and the quantity necessary for the construction of the biodigester.

Table 2. Materials used in the construction of the biodigester.

Materials	Amount	Cost (USD)
Metal tank	1 unit	25.55
½ Quick closing valves	1 unit	6.72
½ Male plug	1 unit	0.64
½ nipple	1 unit	1.95
Teflon	1 m	0.77
Anti-rust paint	1 gallon	14.05
Black paint	1 gallon	23.56
Sandpaper sheet	1 unit	0.46
Spray with black paint	1 unit	5.34
1/2 flex fitting	1 unit	3.17
1⁄2 simple union	1 unit	0.77
½ by 3 eighths fitting bronze	2 units	0.95
½ T union	2 units	1.79
1⁄2 clamp	2 units	0.77
Liquid Teflon	1 unit	2.04
Total		88.53

2.3.2 Construction of the biodigester

A homemade biodigester was built. The container used for the construction of the biodigester was a metal tank with an approximate capacity of 200 liters (0.2 m^3). It had a height of 0.85 m, a diameter of 0.58 m, and a radius of 0.28 m. The type of tank used had only one outlet at the top for capturing biogas for analysis purposes, screwed on and located at the end, as shown in Figure 2.

To raise the temperature inside the biodigester and prevent the incidence of sunlight from stimulating the formation of algae, harming the production of biogas, the entire external part of the container was painted with black paint (Pakistan Science Club, 2023) (Figure 2B).

Figure 2. Anaerobic biodigester: (A) biodigester without black paint; (B) biodigester with black paint.

The construction process of the biodigester, as well as the methodology to determine the amount of biomass necessary to feed them, was based on the work developed by Pereira et al. (2018).

2.4 Biodigester supply

After the construction of the biodigester, it was supplied using bovine manure. The bovine manure was collected in the corral of the Caño Fistola farm located in the rural area of the municipality of Ponedera, Atlántico, Colombia. A single biomass collection was carried out in the place, using 4 buckets with a capacity of 20 liters each.

To determine the amount of mixture necessary to supply half of the biodigesters, 5 kg of biomass was diluted in 5 liters of water in a bucket with a capacity of 20 liters.

Then, this mixture was weighed, subtracting the weight of the bucket, and the volume occupied by the mixture in the bucket was calculated. With the data relating to the volume occupied by the mixture in the bucket and the amount of mixture, a rule of three was made to determine the amount of mixture necessary to supply half of the biodigester.

The calculations carried out are detailed below. Equation (3) was used to determine volumes.

$$V = \pi \times R2 \times \mathrm{H} \qquad \text{Eq. (3)}$$

Where: V = Volume occupied by the mixture in the bucket; H = 0.245 m; R = 0.15 m. Then replacing $V = \pi \times 0.15^2 \times 0.245 = 0.01731$ m^3 = 17.32 L. Tank volume: H = 0.85 m; R = 0.28 m; $V = \pi \times 0.28^2 \times 0.85 = 0.209$ m^3 = 209 L. So, half of the biodigester has a volume equal to 104.5 liters. Using a simple rule of three, we find that 60.4 kg of the mixture is needed to complete half of the biodigester.

The subsequent procedure consisted of weighing the mixture (10 kg), in the defined proportion (1:1) and filling the biodigester until the necessary amount was reached. The procedure of weighing 10 kg of mixture was carried out six times. The dilution ratio was based on the methodology used by Barrena et al. (2019).

An amount of 2g of *Escherichia coli* was added to the substrate to accelerate the proliferation process of methanogenic bacteria. This technique promotes the production of biogas in a shorter period than other animal waste (Divya et al., 2015).

The type of operation of the biodigester was batch, in which only one supply with manure was carried out. The waste remained inside the sealed biodigester, at room temperature (27°C), for 30 days. To determine the volume of biogas produced, a Metrex Daesung industrial meter was used. Biogas volume measurements began 20 days after supplying the biodigester, the average time necessary for the decomposition of organic matter. Flow measurements were made daily over a period of 10 days. The pH of the substrate was measured with a Portable pH/ORP Meter, model HI 8424 from the Hanna brand.

2.5 Estimation of the biogas production potential of the Caño Fistola farm

Once the theoretical and experimental potential for biogas generation of a discontinuous anaerobic biodigester was quantified, the estimate was made for the total number of cattle on the Caño Fistola farm in Ponedera, Atlántico. The above considers a theoretical value of volatile solids of 4.0 $kg_{SV} head^{-1} day^{-1}$ (Table 1). Likewise, the amount of biodigesters required to process all the bovine manure generated on the farm was estimated. With the result obtained, the cost-benefit relationship of the implementation of the alternative was evaluated, considering the electricity costs reported for a residence in ColombiaPlease provide sufficient detail to allow the work to be reproduced by an independent researcher. Methods that are already published should be summarized and indicated by a reference. If you quote directly from a previously published method, use quotes and also cite the source. Any modifications to existing methods should also be described.

3. Results and discussions

3.1 Biogas production estimate

3.1.1 Calculation of daily production of bovine manure on the rural property of Ponedera

According to Herring (2014), an animal with approximately 454 kg of mass generates approximately 0.0269 m^3 (PE) of waste per day. Therefore, when applying Equation (1), considering N° as 150 heads of cattle that make up the Caño Fistola farm, TC as 10 hours of confinement of the animals, a daily amount of 40.35 m^3 of bovine waste produced in the farm resulted in the study area.

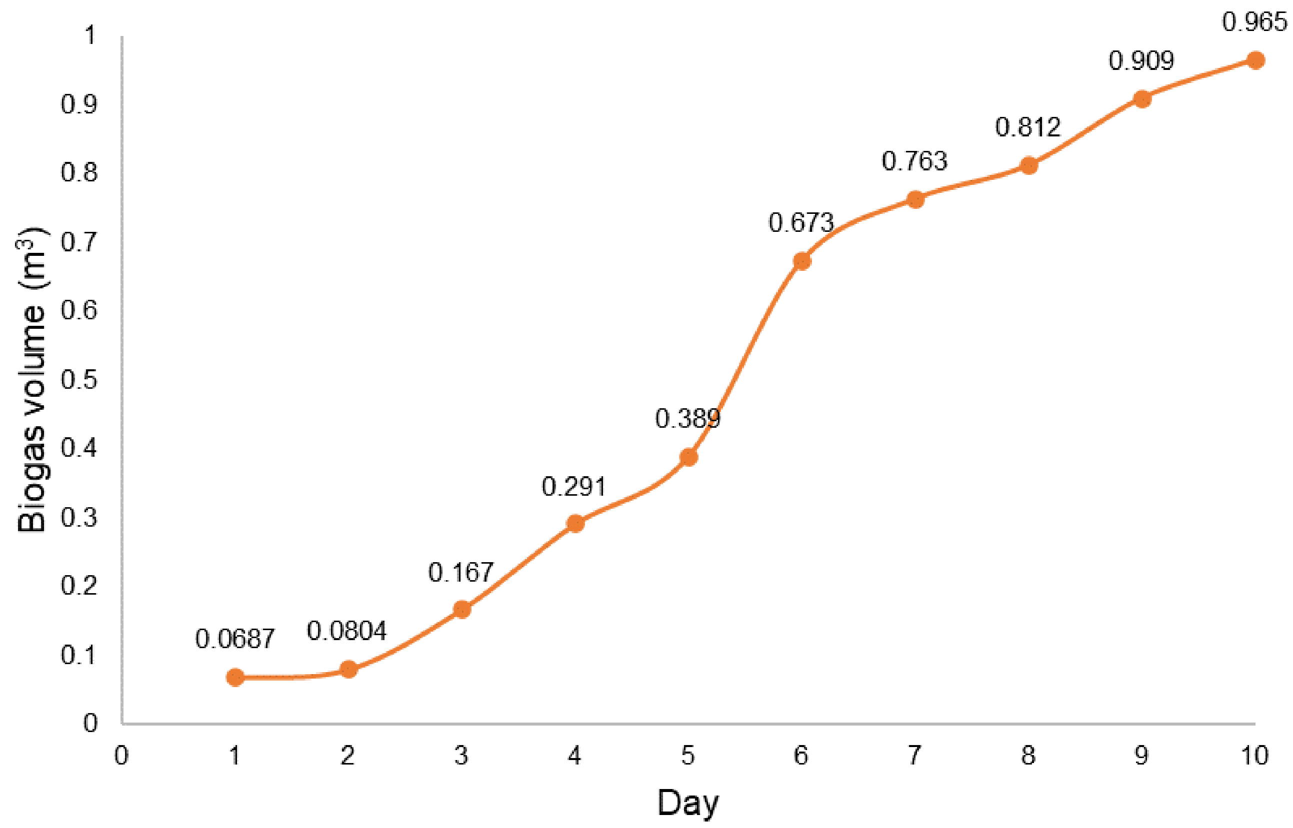
3.1.2 Calculation of the estimated daily theoretical production of biogas from a biodigester

By applying Equation (2) and according to the data in Table 1, the daily biogas production of the discontinuous anaerobic biodigester installed on the Caño Fistola farm in the municipality of Ponedera, Atlántico, Colombia was calculated, considering No. as 150 heads of cattle. bovine. For the IPCC (2019) methodology, the estimate was made considering an average PM weight of 400 kg and the standard PE live weight of 600 kg (Wahyuni et al., 2018); FDC:1; SV: 2.9 kgSV head-1 year-1; FCM: 0.79; B0: 0.13 m3CH4.kgSV-1 y fb: 1; CH4: 60%. The biogas production estimate was 0.4964 m^3 day-1. By using data from the methodology of Mito et al. (2018): PM: 400 kg; PE: 600kg; FDC: 1; SV: 4.0 kgSV head-1 year-1; FCM: 0.78; B0: 0.18 m3CH4.kgSV-1; fb: 0.94; CH4: 60%, the daily estimate result increased to 0.8798 m^3 day-1.

3.1.3 Calculation of the actual biogas production for a biodigester

The daily biogas production (m^3) of a biodigester from bovine manure from the Caño Fistola farm in the municipality of Ponedera, Atlántico, Colombia, after 20 days of filling the biodigester, for 10 days, is shown in the Figure 3.

Figure 3. Daily biogas production.



The results presented in Figure 3 show a daily growth in the volume of biogas, with an average daily production of 0.512 m^3. To record the volume reported for each day, the daily extraction of the gas obtained was carried out. Therefore, the total value produced in 10 days corresponds to the sum of what is shown each day in Figure 3, that is, 5.1181 m^3. Based on the above, when estimating the monthly production of biogas by a biodigester, there would be 15.35 m^3, reaching a total of 184.25 m^3 in one year. It is important to note that these results exceed the study by Durazno-Coronel (2018) by 98.4%, which obtained a daily production of 0.0081 m^3 after 20 days of biodigestion of cattle manure.

It is important to note that in the present investigation, the volatile solids of the manure used have not been experimentally determined. In the work of Durazno-Coronel (2018) 67.32 kg of total solids were used, while in this research it was 30 kg of total solids. However, a higher biogas value was still obtained under what was previously mentioned.

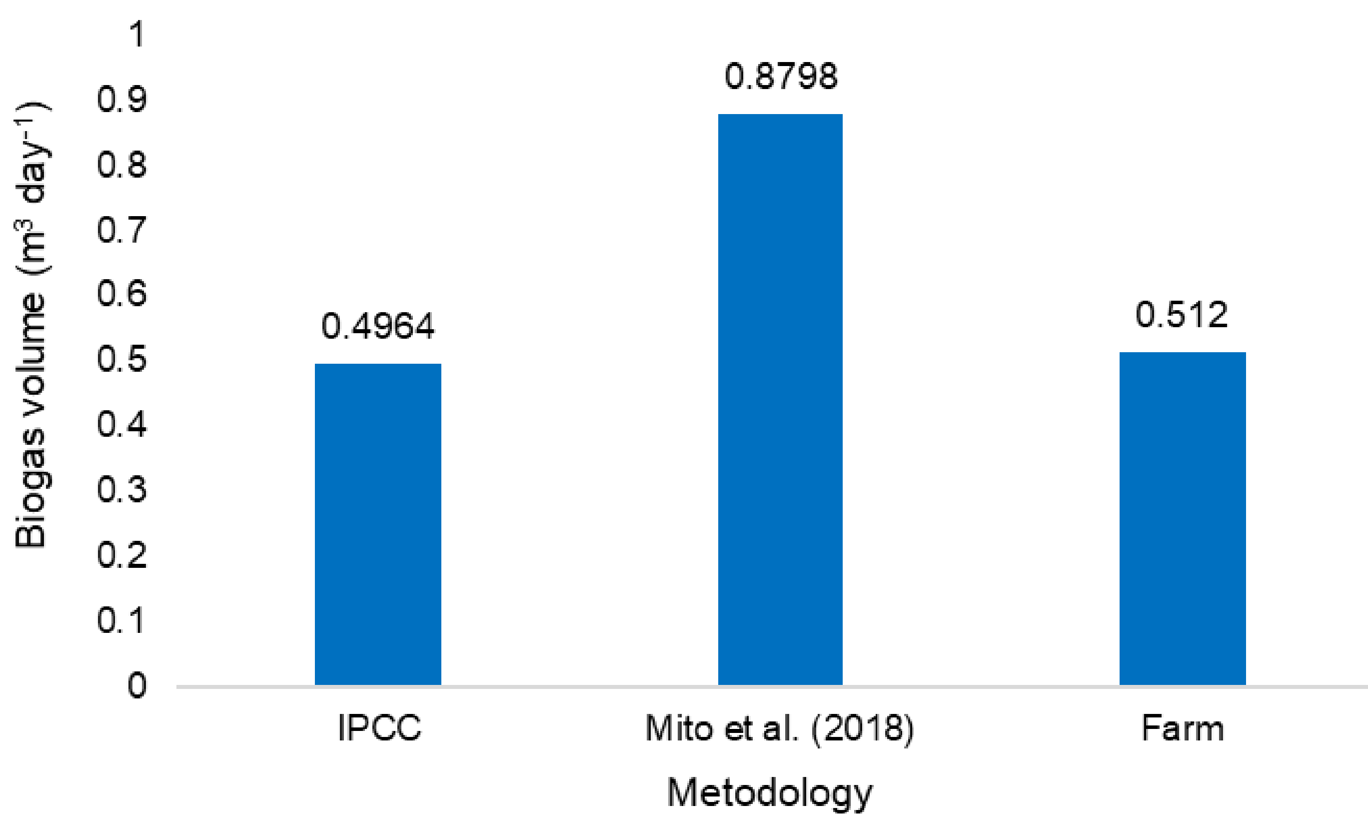
According to the annual production of biogas in the biodigester installed on the Caño Fistola farm, which reached 184.25 m^3, it can be estimated that the cattle waste used generates approximately 865.98 kWh of energy per year. According to the conversion factor proposed by Wahyuni et al. (2018), where 1 m^3 of biogas is equivalent to 4.7 kWh of electrical energy, the volume of 0.512 m^3 per day of biogas produced by the study biodigester could be used to illuminate 60–100-watt lamps for 3 hours.

According to Wahyuni et al. (2018), 1 m^3 of biogas is equivalent to 0.46 kg of LPG gas. Therefore, the 184.25 m^3 of biogas produced would be equivalent to 84.76 kg of LPG. Both the energy and the amount of gas generated by the anaerobic biodigester could be used, for example, to light lamps or to maintain the gas supply in the kitchen of the property under study. These results highlight the potential of the application of small, low-cost manure biodigesters (Table 1) in obtaining biogas to achieve energy self-sufficiency in rural properties.

3.2 Comparison between theoretical production and experimental production of biogas

The results of the estimated theoretical values of biogas production and the actual experimental values are presented in Figure 4.

Figure 4. Results of the theoretical estimates of biogas production and actual experimental estimates for the Caño Fistola farm in Ponedera, Atlántico.



The biogas production observed in Figure 4 by the anaerobic biodigester installed on the Caño Fistola farm in Ponedera presents a value like that estimated with the IPCC method, however, the real value is low concerning that determined with the method of Mito et al. (2018), this difference can be justified by the possible low concentration of methane gas in the biogas. However, the results obtained in this study presented the same order of magnitude compared to the reference methods.

The results obtained can be attributed to various factors and specific conditions of the anaerobic digestion process. Some of the possible reasons include errors associated with sample collection, and the composition of the organic material used in the biodigestion process, which can influence methane production. If the substrate does not contain enough easily digestible organic matter for methanogenic bacteria, methane production tends to be lower (Akanmu et al., 2020).

Furthermore, the efficiency of the system plays a significant role. If the system is not properly designed or operated efficiently, the conditions within the biodigester may not be ideal for the growth of methanogenic bacteria (Hussain and Dubey, 2017).

The pH of the substrate in the biodigester must be maintained within a specific range to allow methanogenic bacteria to thrive. To achieve the best performance of methanogenic microorganisms, the pH should be maintained in the range of 6.7 to 7.5 (Rajendran et al., 2012). If the pH is outside this range, as in the case of this study (9.58), methane production can be affected.

The presence of inhibitory compounds, such as ethylene and acetylene, can affect the growth of methanogenic bacteria, which harms methane production (Webster et al., 2016).

The time that the substrate remains in the biodigester, known as hydraulic retention time (HRT), is crucial to allow methanogenic bacteria to convert the digestion products into methane. If this time is inadequate, methane production may be compromised. In the present study, the HRT was 30 days, although an HRT of 48 hours is the optimal period for the complete degradation of organic matter in the biodigester (Musa and Idrus, 2020).

3.3 Estimation of the biogas production potential of the Caño Fistola farm

In the evaluated discontinuous anaerobic biodigester, 30 kg of total solids were used, which corresponds to 7.5 head of cattle. This estimate takes as a reference a manure production of 4.0 kgSVhead-1day-1. Therefore, if for a single biodigester a production of 184.25 m^3 of biogas was obtained in one year, for the 150 head of cattle on the Caño Fistola farm, the biogas production potential would be 3,685 m^3 per year, equivalent to 17,319.5 kWh of energy per year and 1,695.1 kg of LPG.

If we take as an example an average monthly consumption of 200 kWh in a Colombian stratum 3 home, with a unit value of 825.34 USD/kWh (CREG, 2024), per month the user would pay a total of USD 42.18 without considering subsidies, and per year There would be a total consumption of 2,400 kWh corresponding to a cost of USD 506.15. Considering that the estimated annual gas energy generation potential of the Caño Fistola estate was equivalent to 17,319.5 kWh, it could be said that it would be enough to guarantee energy sustainability of 7.2 times the annual consumption of the property's house.

The above, including the estimate for the manure produced for the 150 head of cattle on the property and a total of 20 discontinuous anaerobic biodigesters. However, if only the average consumption of the house in the year is considered, the assembly of only 3 biodigesters with the manure generated by 23 head of cattle would be sufficient. As the discontinuous anaerobic biodigester used was a homemade type and had a total estimated value of USD 88.53 (Table 1), the 3 biodigesters required an investment of USD 265.58 in total needed, a value lower than the annual energy costs previously estimated.

Table 1. Tabulated values for qualitative parameters.

Category	SV[(1)] $kg_{SV}head^{-1}day^{-1}$	B_0[(2)] $m^3{}_{CH4}.kg_{SV}{}^{-1}$	FCM[(3)] (%)	SM[(4)]	f_b[(5)]	CH_4 (%)	Reference
Dairy cattle	2.9	0.13	0.79	1	-	-	IPCC (2019)
	4.0	0.18	0.78	-	0.94	60	Mito et al. (2018)

[(1)]SV = Volatile Solids; [(2)]B_0 = Methane production capacity from waste; [(3)]FCM = Conversion factor according to management; [(4)]SM = Waste management system factor; [(5)]F_b = Uncertainty correction factor.

It is important to keep in mind that the homemade biodigesters used are low-cost. For its construction, metal containers are used that in some cases can be reused from other processes such as the transportation of hydrocarbons, obtaining them easily, and in some cases, they can even be donated by transport companies. For this reason, the proposed technology can be easily implemented in all types of farms or in remote places where there is little access to other types of energy. Even if it were necessary to purchase all the materials (Table 1), the costs would be lower than the value represented by the acquisition of electrical energy in one year, therefore the investment made would be favorable. According to Issahaku et al. (2024), the low operational and implementation costs of biodigesters are the most attractive advantages of using this equipment. Furthermore, other advantages presented are easy operation, control and maintenance, low operating area and a long useful life.

Finally, it can be said that the preliminary technology proposed in this study presents feasibility in terms of cost-benefit ratio. However, it is essential to continue research along this path, including the optimization of the various operating variables (pH, substrate quality, temperature, nutrients, substrate toxicity, and retention time) of discontinuous anaerobic biodigesters and the inclusion of technologies to convert the biogas generated into electrical energy and thus facilitate the energy self-sufficiency of livestock farms. The implementation of electrical energy-generating technologies such as gas turbines can be considered, after considering the costs, required technical characteristics, as well as the use of standards and safety measures to avoid possible risks to the personnel in charge of the operation. inspection and/or manipulation of the process.

The development of the proposed technology for biogas production presents several challenges that must be addressed to ensure successful and sustainable implementation. Some of the challenges associated with this technology are the availability and quality of organic matter used as a substrate to guarantee the efficiency of the process; lack of knowledge about sustainable, scalable and/or adaptable technologies, as well as insufficient infrastructure can hinder the continued operation of the technology; lack of knowledge about the management of the byproducts of anaerobic digestion in an efficient and environmentally friendly manner; lack of financing and optimization of resources to guarantee the long-term profitability of the process; little knowledge or inefficient transfer of technologies, poor social and cultural acceptance and lack of appropriation by decision-making entities and generators of public policies (Rodríguez et al., 2019; Escobedo and Calderón, 2021; Serrano et al., 2023).

The development of technology for biogas production faces challenges that must be addressed to ensure successful and sustainable implementation. Challenges such as availability and quality of the substrate, lack of knowledge about sustainable technologies, insufficient infrastructure, efficient management of by-products, and lack of financing are critical factors. Furthermore, antibiotics in manure pose risks to the environment and human health, making it crucial to address these aspects to achieve the SDGs, especially in developing countries focused on livestock farming (Hoyos et al., 2024).

The limited studies on small-scale biogas digester monitoring systems suggested by this study align with the work of Budiman (2021), emphasizing the need for further research to advance the success and adoption of domestic biogas technology.

4. Conclusions

Cattle manure anaerobic digestion technology plays a crucial role in sustainable development, maximizing the use of a renewable source of energy and improving efficiency without harming the environment. In addition, it can generate benefits depending on the use of biogas and the cost structure considered.

In this study, an average daily production of 0.512 m^3 of biogas and an accumulated total of 5.1181 m^3 in 10 days was achieved, equivalent to 15.35 m^3 monthly and 184.25 m^3 annually. This translates to 84.76 kg of LPG and approximately 865.98 kWh of energy per year. The estimated potential for the Caño Fistola farm with 150 heads of cattle would be 3,685 m^3 annually, enough to sustain the house 7.2 times, requiring about 20 biodigesters. However, to cover the minimum consumption of the farm (approximately 200 kWh per month, 2,400 kWh per year), 3 biodigesters and 23 heads of livestock would be enough.

This supports the idea that anaerobic digestion with cattle manure, using low-cost homemade biodigesters, can ensure the energy self-sustainability of the property. This favors the cost-benefit relationship, reducing expenses on non-renewable sources.

This research serves as a reference for future studies, contributing to the development of sustainable public policies and complying with SDGs 7 and 13. The proposed biodigesters are replicable anywhere in Colombia and the world.

For future work, it is suggested to deepen the characterization of residues and substrates, including a detailed analysis of the chemical composition, with caution when taking samples and recording data. It is proposed to evaluate the presence and diversity of microorganisms, considering variables such as volatile solids, pH, ashes and C/N ratio.

In addition, it is urged to determine the potential for biogas production through weekly measurements, evaluating the amount of methane generated. Variables related to the process, such as temperature, TRH, and pH, must be considered to improve the efficiency of anaerobic digestion.

This information will serve as a basis to accurately evaluate the performance of biodigesters and design more efficient systems in the future. It is also suggested to explore methodologies to convert biogas into electrical energy and domestic gas, study microbiology, analyze the relationship between exergy, environmental impact, and economy, as well as other areas to improve the technology of anaerobic digestion of animal waste.

Declaration of competing interests

Corresponding The authors declare that they have no conflict of interest.

Author contributions

Régulo Antonia Yepes Maldonado: Methodology, and Investigation

Hugo Hernández Palma: Original draft preparation, Methodology, Data curation.

Andrea Liliana Morenoa Ríos: Writing and review & editing.

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