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Original Article

Electricity generation from wastewater biogas: a case study in Santa Marta, Colombia

Generación de electricidad con biogás de aguas residuales: caso de Santa Marta, Colombia

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Abstract

Introduction: sanitation is one of the main global challenges in building resilience to the effects of climate change and global warming. Wastewater treatment is one of the activities that enables the production of renewable energy through the use of biogas.
Objetive: the objective of this study was to estimate the amount of electricity available in the city of Santa Marta, Colombia, from the production of biogas generated at a wastewater treatment plant and to estimate the avoided emissions with biogas recovery and the non-use of local electricity.
Methodology: a case study was conducted in Santa Marta, Colombia, where the potential for electricity generation from biogas produced at a wastewater treatment plant was estimated. Both the annual electricity generation potential and the avoided CO2eq emissions from using biogas instead of local electricity were calculated.
Results: the results of the case study show significant potential for biogas recovery, with an annual energy generation potential of 5,348.345 MWh. Additionally, it was estimated that 25,101.16 tonnes of CO2eq could be avoided each year.
Conclusions: the use of wastewater for electricity generation is crucial for environmental sustainability, and its application in the circular bioeconomy presents a significant opportunity. This study highlights the importance of implementing sustainable technologies for renewable energy production from unconventional sources, such as biogas from wastewater.

Keywords: emission, energy conversion, methane, renewable energy, sustainability.

Resumen

Introducción: la sanidad es uno de los principales desafíos globales para construir resiliencia frente a los efectos del cambio climático y el calentamiento global. El tratamiento de aguas residuales es una de las actividades que permite la producción de energía renovable mediante el aprovechamiento del biogás generado en dichas plantas.
Objetivo: el objetivo de este estudio fue estimar la cantidad de electricidad disponible en la ciudad de Santa Marta, Colombia, a partir de la producción de biogás generado en una planta de tratamiento de aguas residuales, así como calcular las emisiones evitadas con la recuperación de biogás y el no uso de electricidad local.
Metodología: se realizó un estudio de caso en Santa Marta, Colombia, donde se estimó el potencial de generación eléctrica a partir del biogás producido en una planta de tratamiento de aguas residuales. Se calcularon tanto la cantidad de electricidad que podría generarse anualmente como las emisiones de CO2eq que se evitarían mediante el uso de biogás en lugar de electricidad convencional.
Resultados: los resultados del estudio muestran un significativo potencial para la recuperación de biogás, con un potencial de generación de energía anual de 5,348.345 MWh. Además, se estimó que se podrían evitar emisiones de 25,101.16 toneladas de CO2eq cada año.
Conclusiones: el uso de aguas residuales para la generación de electricidad es fundamental para el cuidado del medio ambiente, y su aprovechamiento dentro de la bioeconomía circular presenta un enorme potencial. Este estudio resalta la importancia de implementar tecnologías sostenibles para la producción de energía renovable a partir de fuentes no convencionales, como el biogás proveniente de aguas residuales.

Palabras clave: emisión, Conversión de energía, Metano, Energía renovable, Sostenibilidad.

Contribution to the literature

Why was it conducted?

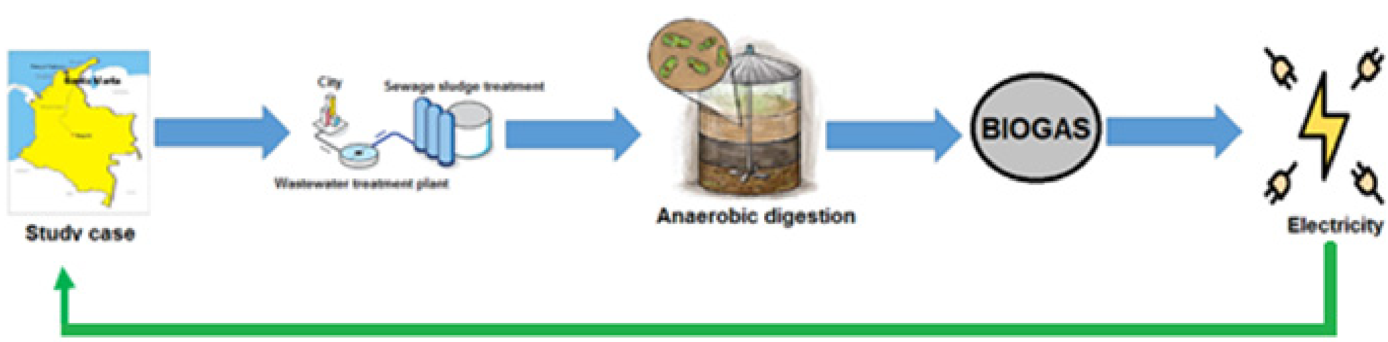
The analysis for the production of electric energy from wastewater represents a sustainable and efficient solution to manage resources and mitigate environmental problems. Capturing and using methane from wastewater prevents its direct release into the atmosphere, which significantly reduces the environmental impact. Energy production can be integrated with wastewater treatment, achieving more sustainable processes and reducing pollutants discharged into the environment. Implementing clean technologies demonstrates social responsibility and commitment to sustainability, improving the image of a city.Treatment plants can generate part or all of the energy they consume, reducing their operating costs.

What were the most relevant results?

The results presented show that the production of methane has the potential to generate 14,653 kWh/d, furthermore the use of biogas for energy production and the non-use of local electricity could avoid the emission of 25,101.16 tonne CO2 eq/year.

What do these results contribute?

Wastewater is considered a valuable resource worldwide and can be an excellent raw material for the production of electrical energy. The use of biogas as a source for electricity production avoids the emission of methane gas into the atmosphere, which has a higher pollution potential compared to carbon dioxide.



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Introduction

Rapid urbanisation, population growth and technological development have led to various changes in the lifestyle, production and consumption patterns of the population (1). This has led to an increase in waste, causing ecological imbalance and damage to the environment (2). Another major problem caused by population growth is the pressure on water resources and sanitation facilities, resulting in the generation of wastewater (3). Wastewater treatment is important for hygiene and sanitation to prevent diseases and epidemics (4).

Domestic and industrial activities generate wastewater. The World Health Organization (WHO) states that fulfilling basic needs such as drinking, personal hygiene, food preparation, and household cleaning requires between 50 and 100 liters of water per person each day (5). Up to 90% of this drinking water ends up as wastewater (6). The availability of domestic wastewater is constant, so reuse and treatment is necessary to avoid contamination of natural water resources, recycle nutrients and prevent pollution (7).

The 2017 United Nations World Water Development Report sheds light on the stark disparities in wastewater treatment across different economic tiers of nations. High-income countries lead the way, treating approximately 70% of their municipal and industrial wastewater, thanks to more advanced infrastructure, technological capacity, and resources. In upper-middle-income countries, however, the percentage of treated wastewater drops significantly to 38%, while lower-middle-income nations manage to treat only 28%. The situation becomes even more concerning in low-income countries, where a mere 8% of wastewater receives proper treatment, largely due to the high costs associated with building and maintaining treatment facilities (8). This financial burden often leaves such nations unable to invest in the necessary systems, resulting in the majority of wastewater being released into the environment untreated. Globally, these figures reveal that over 80% of all wastewater generated is discharged directly into rivers, lakes, and oceans without undergoing any form of treatment, posing serious risks to human health, ecosystems, and water resources. The gap between countries in wastewater management highlights the urgent need for more equitable access to clean water technologies and sustainable solutions worldwide (8).

By 2014, in Colombia, only 517 municipalities (51%) reported sewerage coverage in urban areas, while only 210 plans (20%) reported sewerage coverage in rural areas (9). Therefore, coverage of sanitation services must go hand in hand with progress in treatment. The latest data from the Ministry of Housing, City and Territory indicated a growth between 2002 and 2022 in the percentage of treated urban wastewater in Colombia from 8 to 54.30%. It is also expected that by 2030 the percentage will be 68.6%, all this with the strategic objectives and commitments acquired by the country in the fulfilment of the Sustainable Development Goals (10).

In a global context, the United Nations (UN) has established the 2030 Agenda, which includes 17 Sustainable Development Goals (SDGs) (11) aimed at achieving greater prosperity through a more sustainable world. SDG 6 focuses on safe drinking water and sanitation, while SDG 7 emphasizes affordable and clean energy, highlighting the significance of basic sanitation and energy recovery from waste, respectively.

One method of treating wastewater in treatment plants involves utilizing anaerobic UASB (Upflow Anaerobic Sludge Blanket) reactors. These reactors are regarded as one of the most advanced anaerobic treatment processes developed so far (12).

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During the wastewater treatment process, anaerobic digestion of wastewater produces biogas through the decomposition of organic matter by microorganisms in the absence of oxygen (13). The CH_4 present in biogas is approximately 21-28 times more harmful to the environment than CO_2 (14), and the flaring of biogas in energy production avoids emissions of this gas. Biogas consists mainly of methane (CH_4) and carbon dioxide (CO_2), two highly flammable and energetic gases (15). This renewable fuel can be used to produce electricity, heat or even as a vehicle fuel (16). Electricity production in wastewater treatment plants can be used for own consumption and in some cases surplus electricity can be sold (17).

Bilotta et al. (18) quantified the amount of electricity produced and estimated the amount of emissions avoided in a wastewater treatment plant in Brazil. The results obtained indicate an electricity production of 65,280.3 kWh/month and an avoided emission of 603.3 kg CH_4/d with biogas recovery. Aragão and Moreira (19) investigated the potential for generating electricity from biogas produced at a Wastewater Treatment Plant in Bahia, Brazil. During the period analyzed, the plant showed a methane production of 1,706.9 m³/day; average available electrical energy of 76,495.5 kWh/m; avoided methane emissions of 1,109.4 kg CH_4.

Therefore, the aim of this study is to estimate the production of electricity from wastewater treatment in the city of Santa Marta, Colombia, and to calculate the amount of emissions avoided through the recovery of biogas and the non-use of local electricity.

Material and methods

Santa Marta, the city featured in this case study, serves as the capital of the Magdalena department in Colombia (Figure 1). Situated along the shores of its namesake bay on the Caribbean Sea, the city's geographical coordinates are 11º 14′ 50″ N latitude and 74º 12′ 06″ W longitude. Covering a total area of 2,393 km², Santa Marta is bordered by the Caribbean Sea to the north and west, the department of La Guajira to the east, and the municipalities of Aracataca and Ciénaga to the south.

This work takes a case study approach and is divided into three stages:

Estimation of methane production, estimation of available energy, calculation of avoided emissions.

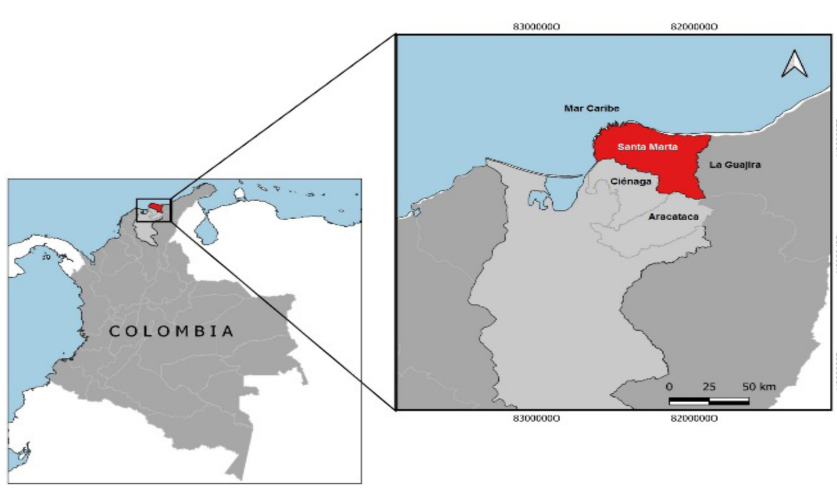

Figure 1. Location of Santa Marta city.

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Estimation of methane production

For the estimation of methane production, the model was structured according to the methodology of (20) (Figure 2).

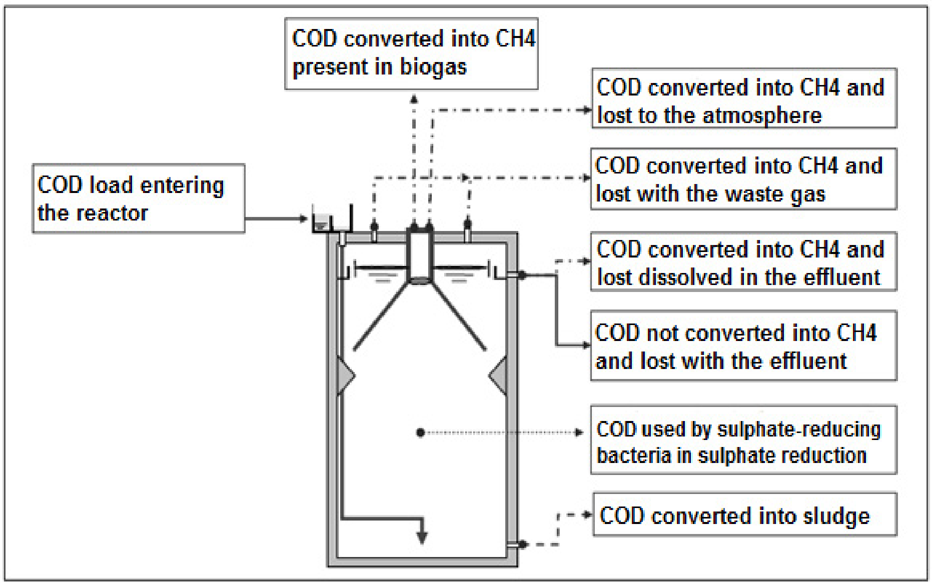

Figure 2. Pathways for COD conversion and methane production in UASB reactors.

The estimated COD load removed in the system can be calculated from Equation 1.

$$COD_{rem} = Pop * QPC_{COD} * E_{COD} \quad (1)$$

Where:

CODrem = daily mass of COD removed from the system (kg COD rem/d).

Pop = Population.

QPC_{COD} = COD contribution per capita (kg COD/inhab*d).

E_{COD} = COD removal efficiency.

The sludge production in the UASB reactors can be estimated by Equation 2.

$$COD_{sludge} = Y * K_{STV-COD} * COD_{rem} \quad (2)$$

Where:

CODsluge = daily mass of COD converted to sludge (kg sludge COD/d).

Y = solids production coefficient (kg STV/kg COD rem).

$K_{STV\text{-}COD}$ = conversion factor from STV to COD.

The estimation of the sulphate load reduced to sulphide can be done by Equation 3.

$$CO_{SO4\ converted} = Q_{Av} * C_{SO4} * E_{SO4} \quad (3)$$

Where:

CO_{SO4} converted = SO_4 load converted to sulphur (kg SO_4/d).

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QAv= average influent waste water flow to the reactor (m^3/d).

C_{SO4} = average SO_4 concentration in the influent (kg SO_4/m^3).

E_{SO4}= SO_4 reduction efficiency.

The average wastewater flow per capita is given by Equation 4

$$Q_{Av} = Q_{pc} * r * Pop \quad (4)$$

Where:

r = Return flow coefficient.

Qpc = Per capita water consumption (l/inhab*d).

The COD load used for sulphate reduction can be estimated using Equation 5.

$$COD_{SO4} = C_{SO4\ converted} * K_{COD-SO4} \quad (5)$$

Where:

COD_{SO4} = daily mass of COD used by the sulphate-reducing bacteria in sulphate reduction (kg COD S_{O4}/d).

$K_{COD\text{-}SO4}$ = COD consumed in sulphate reduction.

The determination of the daily mass of COD converted to CH_4 can be calculated by Equation 6.

$$COD_{CH_4} = COD_{rem} - COD_{sluge} - COD_{SO_4} \quad (6)$$

Where:

COD_{CH4} = daily mass of COD converted to methane (kg COD/d).

The estimate of the daily amount of methane produced is given by equation 7.

$$Q_{CH_4} = \frac{COD_{CH_4} * R * (273+T)}{P * K_{COD}} \quad (7)$$

Where:

Q_{CH4} = theoretical maximum volumetric methane production (m^3/d).

P = atmospheric pressure (1 atm).

K_{COD} = COD corresponding to one mole CH_4.

R = gas constant (0,08206 atm*L/mol*K).

T = operating temperature of the reactor (°C).

To calculate the actual methane estimate, it is necessary to calculate the possible losses in the gas phase, such as: exhaust and other losses and liquid phase, according to Equations 8, 9 and 10.

$$Q_{W-CH_4} = Q_{CH_4} * P_W \quad (8)$$

$$Q_{O-CH_4} = Q_{CH_4} * P_O \quad (9)$$

$$Q_{L-CH_4} = Q_{Av} * P_L * f_{CH_4} * \left(\frac{R * (273+T)}{P * K_{DQO}}\right) \quad (10)$$

Where:

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$Q_{W\text{-}CH4}$ = gas phase methane loss, with waste gas (m^3/d).

Pw = percentage of gas phase methane loss, with waste gas (%).

$Q_{O\text{-}CH4}$ = other gas phase methane losses (m^3/d).

Po = percentage of other gas phase methane losses.

$Q_{L\text{-}CH4}$ = liquid phase methane loss, dissolved in the effluent (m^3/d).

P_L = liquid phase methane loss, dissolved in effluent (kg/m^3).

f_{CH4} = conversion factor from mass of methane to mass of COD.

Equation 11 was used to calculate the actual methane production.

$$Q_{Real-CH_4} = Q_{CH_4} - Q_{W-CH_4} - Q_{O-CH_4} - Q_{L-CH_4} \quad (11)$$

Where:

$Q_{REAL\text{-}CH4}$ = actual methane production available for energy recovery (m^3/d).

The actual methane production converted to a normal standard is given by Equation 12.

$$Q_{N-RealCH_4} = \left(\frac{Q_{Real-CH_4} * P}{T}\right) * 273 \quad (12)$$

Where:

$Q_{N\text{-}RealCH4}$ = Actual methane production converted to normal pattern.

P = is the local pressure, in atm,

T = is the local temperature, in K.

Estimation of available energy

The model was structured according to the methodology of (21). To transform the biogas energy into kWh/m³, Equation 13 was used.

$$PCI_d = PE_{CH_4} * LHV_{CH_4} * K \quad (13)$$

Where:

PCId = Lower Available Calorific Potential in kWh/m³.

PE_{CH4} = Specific gravity in kg/Nm³.

LHV_{CH4} = Lower Calorific Potential in kcal/kg.

K = Conversion constant between kcal to kWh.

To calculate the effective electrical power, the overall efficiency value of Otto cycle engines was used and using Equation 14, the final electrical power was determined.

$$PE = Q_{N-RealCH_4} * PCI_d * Ef \quad (14)$$

PE = Electrical energy available from methane, kWh/d.

Ef = Conversion efficiency.

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Calculation of avoided emissions

The anaerobic digestion process is related to biogas, which is a mixture of gases, mainly methane and carbon dioxide, but can also contain hydrogen, nitrogen, oxygen and sulphuric acid. In this study, methane generation was considered to estimate the reduction of greenhouse gas emissions. The result of the methane production calculation was used to calculate the avoided methane emission, as this amount of methane would be released directly into the atmosphere. Furthermore, with the generation of energy from biogas, CO_2 emissions associated with electricity generation in the National Interconnected System, which were 0.126 tonne CO_2/MWh in 2021 according to (22) will also be avoided. Thus, the avoided GHG emissions in this study were accounted for by considering the potential of methane recovered and the amount of avoided CO_2 emissions related to the electricity generated. The calculation of methane emissions was based on the document "Guidelines for National Greenhouse Gas Inventories", (23). Equation 15 was used to calculate methane emissions.

$$E_{CH_4} = EF\left(COD_{rem} - COD_{sluge}\right) - m_{CH_4} \qquad (15)$$

Where:

E_{CH4} = CH4 emission (kg CH_4/d).

EF = Emission factor (kg CH_4/kg COD rem).

CODrem = daily mass of COD removed from the system (kg COD rem/d).

CODsluge = daily mass of COD converted to sludge (kg sludge COD/d).

mCH_4: CH_4 removed in energy use (kg CH_4/d).

Equation 16 was used to calculate CH4 removed in energy use.

$$m_{CH_4} = \frac{P * V * MM_{CH_4}}{R * (T + 273)} \qquad (16)$$

Where:

P = atmospheric pressure (1 atm).

V: Maximum volumetric CH_4 production (m³/d)

MM_{CH4}: Molecular mass CH_4 = 0.016 kg/mol

R = gas constant (0,08206 atm*L/mol*K).

T: Reactor operating temperature (°C).

The main variables used to estimate methane production, energy potential and methane emissions are the following table 1.

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Table 1. Parameters used for the study

Variable	**Value**
Population	495,072 inhab (24)
COD contribution per capita	0.1 kg COD/inhab*d (20)
COD removal efficiency	0.65 (20)
Coefficient of solids production	0.15 kg STV/kg COD rem (7)
STV to COD conversion factor	1 kg STV = 1.42 kg COD sludge (20)
Concentration of SO_4 in the affluent	0.06 kg SO_4/m^3 (20).
Sulphate reduction efficiency	0.75 (20)
Coefficient of return	0.8 (7)
Per capita water consumption	160 l/inhab*d (Assumed)
COD consumed in sulphate reduction	0.667 kg COD SO_4/kg SO_4 (7)
COD corresponds to 1 mole of methane	0.064 kg COD CH_4/mol (20)
Biological reactor temperature	25 °C (20)
Loss of CH_4 in the gas phase	0.05 (20)
Other losses of CH_4 in the gas phase	0.05 (20)
Loss of CH_4 dissolved in the effluent (P_L)	0.02 kg/m^3 (20)
Theoretical conversion factor of COD in CH_4	4 kg COD/kg CH_4 (20)
Specific weight of CH_4	1.0268 kg/Nm^3 (25)
Lower calorific value of CH_4	6,253.01 kcal/kg (25)
Conversion efficiency	0.35 (7)
Emission factor	0.19 kg CH_4/kg COD rem (20)

Results

Using equations 1-14 and the variables mentioned above it was possible to calculate the variables required to estimate methane production and available energy. Table 2 shows the results of the calculation of the variables used in this stage of the research.

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Table 2. Calculated results

Variable	**Value**
COD removed (COD_{rem})	32,179.68 kg COD rem/d
COD converted to sludge (COD_{sluge})	6,854.27 kg COD sluge/d
Concentration of SO_4 converted in sulphur ($CO_{SO4\ converted}$)	2,851.62 kg SO_4/d
Average wastewater flow (Q_{Av})	63,369.22 m^3/d
COD ratio used by bacteria that SO_4 (COD_{SO4})	1,902.03 kg COD SO_4/d
COD converted to CH_4 (COD_{CH4})	23,423.38 kg COD CH_4/d
Maximum volumetric production of CH_4 (Q_{CH4})	8,949.88 m^3/d
Losses of CH_4 in the gas phase (Q_{W-CH4} + Q_{O-CH4})	894.98 m^3/d
Loss of CH_4 dissolved in effluent (Q_{L-CH4})	1,937.03 m^3/d
Available flow rate ($Q_{REAL-CH4}$)	6,117.87 m^3/d
Standardized flow available ($Q_{N-RealCH4}$)	5,604.63 Nm^3/d
Lower calorific value available from CH_4 (PCI_d)	7.47 kWh/m^3
Electrical power available (PE)	14,653 kWh/d

The monthly residential electricity consumption in the urban part of the city of Santa Marta for the year 2021 is shown in Table 3.

Table 3. Monthly electricity consumption in Santa Marta

Month	**Consume (kWh)**
January	45,489,691
February	44,071,729
March	42,446,335
April	47,261,489
May	45,309,825
June	48,477,008
July	47,660,791
August	51,370,069
September	47,710,985
October	49,661,279
November	49,172,372
December	47,517,777

The results of the calculation of the potential emissions avoided by methane recovery and not using local electricity are presented in Table 4.

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Table 4. Result of variables calculated for CH_4 emission.

Variables	Results obtained
CH_4 Removed in the Energetic Use (m_{CH4} Theoretical)	5,855.85 kg CH_4/d
CH_4 Removed in the Energetic Use (m_{CH4} Calculated)	3,667.07 kg CH_4/d
Total emission of CH_4 (E_{CH4} without the use of biogas)	4,811.93 kg CH_4/d
Total emission of CH_4 (E_{CH4} with the use of biogas)	1,144.76 kg CH_4/d
Avoided GHG emissions due to methane recovery	24,427.27 tonne CO_2 eq/year
GHG emissions avoided due to non-use of local electricity	673.89 tonne CO_2 eq/year
Total GHG emissions avoided per year	25,101.16 tonne CO_2 eq/year

Discussion

With the results obtained, the available electricity from methane is 5,348.345 MWh/year it is possible to conclude that the energy from methane generated from wastewater in Santa Marta can only supply 0.94% of the energy consumed in the year 2021. To increase the production of electrical energy, other types of raw materials can be considered for the production of biogas such as: urban solid waste, agricultural waste, animal waste and other alternatives such as the production of microalgae cultivated in wastewater, wind energy and solar energy.

The calculation of the mass of methane removed in biogas energy recovery (mCH_4) was calculated in two ways: using the maximum volumetric methane production (QCH_4), considered as theoretical production, and using the available methane flow ($QN\text{-}Real\text{-}CH_4$), considered as actual methane production. The first scenario resulted in 5,855.84 kg CH_4/d (theoretical mCH_4) and the second scenario resulted in 3,667.07 kg CH_4/d (calculated mCH_4), which is approximately 37% less than the theoretical value. In a study carried out in Curitiba - Brazil for a wastewater treatment plant, the total CH4 emission without biogas recovery was 1,549.5 kg CH_4/d and with biogas recovery it was 603.3 kg CH_4/d (18). Another study carried out in Bahia - Brazil showed that the total CH4 emission without biogas recovery was 1,290.2 kg CH_4/d and with biogas recovery it was 180.8 kg CH_4/d (19).

The difference between the theoretical value and the real value is due to methane losses in the liquid and gaseous phases, as well as the part consumed by the bacteria in the conversion of sulphate to sulphide during the wastewater treatment process. In this way, the calculated mCH_4 provides a more accurate answer.

By analyzing the mass of methane removed through biogas energy utilization, two emission scenarios were evaluated: one without biogas use and the other with biogas recovery. The findings indicated that utilizing biogas can significantly reduce total methane emissions (E_{CH4}) from 4,811.83 kg CH_4 per day to 1,144.76 kg CH_4 per day. Consequently, this results in avoided methane emissions amounting to 3,667.07 kg CH_4 per day.

However, based on the stoichiometry of the CH_4 combustion reaction (Equation 17), it is possible to observe that 16 g CH_4/mol are consumed, while 44 g CO_2/mol are released. As a result, it is estimated that the burning of 3,667.06 kg CH_4/d (calculated actual RCH_4) results in the formation of 10,084.43 kg CO_2/d.

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$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (17)$$

Knowing that the global warming potential of CH_4 is 21 times that of CO_2, the mass corresponding to the methane emission avoided (calculated actual mCH_4) would be 77,008.47 kg CO_2 eq/d. Subtracting from this value the mass of CO_2 formed in the CH_4 combustion reaction (Equation 17), the estimated GHG emission reduction would be 66,924.03 kg CO_2 eq/d.

Colombia in its Nationally Determined Contributions (NDCs) set its target to reduce greenhouse gas emissions by 51% by 2030 and achieve carbon neutrality by 2050. The results of the study show that the avoided carbon dioxide emissions amount to 25,101.16 tonnes CO_2/year, which represents 0.014% of the 2030 target proposed by the Colombian government. In April 2024, the price of electricity on the stock exchange was 1,500 COP/kWh. Assuming that 1 Colombian peso (COP) is 0.00022 USD, the revenues from the sale of electricity would be 1,764,954 USD/year.

Conclusion

Wastewater is considered a valuable resource worldwide and can be an excellent raw material for the production of electrical energy. To do this, it is necessary to obtain accurate data on the annual generation of wastewater. The use of biogas as a source for electricity production avoids the emission of methane gas into the atmosphere, which has a higher pollution potential compared to carbon dioxide. The results presented show that the production of methane has the potential to generate 14,653 kWh/d, furthermore the use of biogas for energy production and the non-use of local electricity could avoid the emission of 25,101.16 tonne CO_2 eq/year. Future work may focus on conducting an economic feasibility assessment for decision making in renewable energy project initiatives, in order to determine the estimation of capital, operating and maintenance expenses, and the evaluation of various economic indicators such as levelized cost of energy (LCOE), net present value, IRR and payback period (PBP).

CRediT authorship contribution statement

Conceptualization - Ideas: Jorge Eduardo Infante Cuan, Sergio Daniel Martínez Campo, Leandro Raúl Rozo Martínez, Maria Margarita Rosa Sierra Carrillo. Data Curation: Jorge Eduardo Infante Cuan, Maria Margarita Rosa Sierra Carrillo. Formal analysis: Jorge Eduardo Infante Cuan, Sergio Daniel Martínez Campo. Investigation: Jorge Eduardo Infante Cuan. Methodology: Jorge Eduardo Infante Cuan, Sergio Daniel Martínez Campo, Leandro Raúl Rozo Martínez. Project Management: Lucio G. Cruz-Velasco. Resources: Lucio G. Cruz-Velasco , Sara M. Gómez-Rodríguez, Yeleman F. Valbuena-Muñoz. Supervision: Lucio G. Cruz-Velasco. Validation: Lucio G. Cruz-Velasco , Sara M. Gómez-Rodríguez, Yeleman F. Valbuena-Muñoz. Visualization - Preparation: Lucio G. Cruz-Velasco , Sara M. Gómez-Rodríguez, Yeleman F. Valbuena-Muñoz. Writing - original draft - Preparation: Lucio G. Cruz-Velasco , Sara M. Gómez-Rodríguez, Yeleman F. Valbuena-Muñoz. Writing - revision and editing - Preparation: Lucio G. Cruz-Velasco , Sara M. Gómez-Rodríguez, Yeleman F. Valbuena-Muñoz.

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