ESJ Natural/Life/Medical Sciences

Assessment of the Potential for Greenhouse Gas Emission Mitigation by the Methanization of Slaughterhouse Waste in the District of Abidjan (Côte d'Ivoire)

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Doi:10.19044/esj.2022.v18n36p34

Submitted: 17 October 2022
Accepted: 17 November 2022
Published: 30 November 2022

Cite As:
Kone T. Mangoua-Allali A.L.C., Ama-Cauphys A. B., Kone P.H., Ouattera P.J. & Coulibaly L. (2022). *Assessment of the Potential for Greenhouse Gas Emission Mitigation by the Methanization of Slaughterhouse Waste in the District of Abidjan (Côte d'Ivoire)*. European Scientific Journal, ESJ, 18 (36), 34. https://doi.org/10.19044/esj.2022.v18n36p34

Abstract

Abattoirs are a source of huge waste that contributes to global greenhouse gas (GHG) emissions and, thus, to global warming and climate change. This study aimed to evaluate the GHG emission mitigation potential of a biodigester to be installed at the abattoir of Port-Bouët in the District of Abidjan. Mathematical methods developed by Hashimoto, Gwogon, and Amahrouch and an empirical method were used to assess this mitigation potential. The results showed that regardless of the methods, biogas volumes increased from 2013 to 2017 and decreased in 2018. The highest daily biogas production was obtained in 2017 for all the methods. According to Hashimoto's method, the biogas volume was 564.50 m^3 in a biodigester of 2792.64 m^3. Gwogon's method led to a biogas volume of 724.15 m^3 for a 2228.14 m^3 biodigester. The calculated volume of biogas with the Amahrouch method was 557.03 m^3 for a 2785.17 m^3 biodigester. The empirical method showed a maximum biogas volume of 631.31 m^3. The amount of CO_2 avoided per kilogram of dung ranged from 41579.88 to 71561.17 kg CO_2e, 41643.46

to 71670.58 kg CO_2e, 41689.19 to 71749.30 kg CO_2e for Gwogon, empirical and Hashimoto methods, respectively. The values ranged from 41694.30 to 71758.10 kg CO_2e for the Amahrouch method. These results show a biodigester's tremendous environmental and economic potential for treating the waste of the slaughterhouse of Port-Bouët.

Keywords: Biodigester, Biomethanization, Biogas, Methane, Greenhouse gases emissions, Abattoir, Waste

Introduction

Both renewable and non-renewable energy are fundamental pillars of economic, political, and social development (Desarnaud, 2016; Berahab, 2019). Indeed, energy allows populations to benefit from comfort, productivity, and mobility. Moreover, access to affordable energy for all is part of the Sustainable Development Goals to eradicate poverty, protect the planet and ensure prosperity for all by 2030 (UNDP, 2015).

Unfortunately, in Africa, despite abundant reserves of fossil and renewable energy resources (Berahab, 2019), nearly 600 million people live without access to energy (Bass and Tchanche, 2020). In this continent, a pronounced energy deficit is marked by untimely power outages (Capri, 2019) and a lack of fuel gas.

Therefore, biomass such as wood and charcoal are the primary energy sources for most African populations (Forestry Economics and Policy Division, 2008; Madon, 2017). However, using these sources contributes to deforestation, thus to the disappearance of forest cover (MAP, 2009).

It is necessary to be able to quantify greenhouse gas (GHG) emissions and their relative impact on the environment, but also to identify the main sources and solutions to achieve the mitigation targets to fit into the Sendai framework (UNISDR, 2015). Also, for some years, the United Nations encouraged countries to turn to renewable energy sources (Ekouedjen, 2017).

Thus, biomethanization is a promising environmental approach to reducing pressure on forest resources and investing in fossil fuels (Bardou et al., 2013). To this end, biomethanization allows for the stabilization of organic matter from waste while producing biogas that can be used as a renewable energy source and mitigating GHG emissions (Joseph et al., 2009; ATEE, 2011; Rivard, 2015).

Studies by Guarino and Carotenuto (2016) showed that the biogas produced in the biomethanization process contains in generally approximately 50% to 75% methane (CH_4) and 25% to 50% carbon dioxide (CO_2). Biomethanization is particularly suitable for wet waste rich in organic matter with cellulosic dominance, such as animal waste, manure, litter, etc. (Farinet, 2012; Rakotoniaina, 2012).

The situation in Côte d'Ivoire, regarding energy access, is not very different from that of other African countries. Indeed, electricity is mainly produced by hydroelectric plants and thermal plants using charcoal, natural gas, etc. (Koua et al., 2015). However, energy sources for cooking remain firewood and charcoal (Kouadio, 2019). They account for two-thirds of total energy consumption (Koua et al., 2015).

Yet, the country has significant quantities of urban waste, including slaughterhouse waste, that can be recovered for energy. Managing this waste remains problematic. For example, at the Port-Bouët slaughterhouse, liquid waste (blood, sewage) is discharged through septic tanks into the lagoon without any prior treatment, while solid waste (litter, dejecta, food scraps, horns, bones, muttonchops, etc.) is mostly transported and disposed of at the municipal landfill.

These practices can have adverse environmental consequences (Zalaghi et al., 2014), whereas slaughterhouse waste could be transformed through biomethanization to produce biogas and digestate (De, 2012).

Indeed, waste treatment for methane recovery could help mitigate waste-induced GHG emissions and thus reduce global warming and climate change.

The country is preparing to mitigate its GHG emissions by up to 30.41% by 2030, as committed in its Nationally Determined Contribution (NDC) under the Paris Agreement on climate (République de Côte d'Ivoire, 2022). Thus, a set of mitigation measures was adopted in priority sectors.

In this regard, especially for the waste sector, the recovery and use of methane through biological waste treatment could have a high potential for GHG emissions mitigation. This study reflects on the potential for reducing GHG emissions through the methanization of the abattoirs' waste as a contribution to NDC implementation. The objective of this study is to evaluate the potential for GHG emission mitigation by a biodigester to be installed at the abattoir of Port-Bouët in the District of Abidjan as a pilot project. More specifically, it aims to: (i) estimate the daily biogas production from 2013 to 2018 according to the mathematical methods of Hashimoto, Gwogon, and Amahrouch, and an empirical method, (ii) evaluate the environmental benefits of the biodigester by estimating the avoided GHG emissions according to the methods mentioned above.

Material and methods

Site of study

This study was conducted at the slaughterhouse of Port-Bouët located in the city of Port-Bouët in the Autonomous District of Abidjan. This city covers an area of 110 km^2 and is surrounded by the Ebrié Lagoon and the Atlantic Ocean. The slaughterhouse of Port-Bouët is located in the center of the city, not far from the public hospital, the Town Hall, and the Port-Bouët I Sudents' residence (Diarrassouba, 2011). The slaughterhouse was established in 1959 to slaughter an average of 50 to 60 steers per day. However, to back to 2018, the slaughterhouse reached 500 cattle slaughtered per day (Dagnogo, 2018).

The biodigester feeding substrate

The substrate used to feed the biodigester was composed of animal excrement and other waste from the slaughtering process. The choice of the abattoir waste to carry out the current study was justified by their availability and ease of use by the microorganisms (chemical nature, ease of enzymatic hydrolysis of polymers). Also, their granulometry and water content (possibility of pumping or not) are advantageous to facilitate fermentation. Moreover, these wastes have a high methanogenic potential.

According to Dagnogo (2018), the waste produced at the slaughterhouse between 2013 and 2018 consisted mainly of litter and dung (Table I). Of these wastes, dung was be used to assess the biogas production potential at the site of the slaughterhouse of Port-Bouët. Indeed, the litter produced is used by residents as fertilizer for market gardening, while the dung is transported and discharged at the municipal landfill.

Table 1. Evolution of waste production (Litter and Dung) at the abattoir of Port-Bouët from 2013 to 2018

Year	Liter (t/y)	Dung² (t/y)	Total (t/y)
2013	3458	3420	6878
2014	3484	3983	7467
2015	3850	4142	7992
2016	3750	5260	9010
2017	3680	5886	9566
2018	6360	5600	11960

t = ton y= year

Methods

Designing the biodigester and estimating biogas and methane production by mathematical methods

Mathematical method of Hashimoto

The method developed by Hashimoto has been used in several studies, including those of Coudure and Castaing (1997), and Peter (2009). This method allows for determining the total volume of the biodigester and the biogas, including several parameters (relations from 1 to 9).

- **Total volume Vt (m^3) of the biodigester:**

The total volume Vt (m^3) of the biodigester is the sum of the useful volume (Vu) and the biogas volume (Vb), as follows:

$$V_t = V_u + \mathrm{Vb} \tag{1}$$

Where:

Vt= total volume of the biodigester (m^3);
Vu= useful volume of the biodigester (m^3); and,
Vb= biogas volume (m^3).

- **Biogas volume (V_b)**

The volume of biogas Vb (m^3) potentially produced is given by equation (2):

$$V_b = P_S \times V_u = \frac{B_0 \times S \times V_u}{HRT}\left[1 - \frac{K}{HRT \times \mu_m - 1 + K}\right] \tag{2}$$

Where:

Vb= biogas volume (m^3);
Ps= specific biogas production;
Vu= useful volume (m^3);
S= volumetric load;
HRT= hydraulic retention time;
K= inhibition constant; and,
µm= growth rate per day.

K depends on the load S according to equation (3), while the microorganisms daily growth rate (µm) varies linearly with temperature shown according to equation (4):

$$K = 0,8 + 0,0016 \times e^{0,06 \times S} \tag{3}$$

$$\mu_m = 0,013(T) - 0,129 \tag{4}$$

- **Biogas specific production (P_s)**

The expression of the specific production Ps is then given by equation (5).

$$P_S = \frac{B_o \times S}{HRT}\left[1 - \frac{K}{HRT \times \mu m - 1 + K}\right] \tag{5}$$

- **Volumetric load (S)**

The Volumetric load (S) is given as follows:

$$S = \frac{m \times C}{V_u} \tag{6}$$

Where:

S= volumetric load;
m = mass of the substrate to be digested;
C= concentration; and,
Vu = useful volume (m^3).

- **Useful volume of the biodigester (V_u)**

The useful volume (Vu) of the biodigester is a function of the flow rate (Q) and the hydraulic retention time (HRT):

$$V_u = HRT\ \times\ Q\ = \frac{HRT\ \times m \times (1 + x)}{\rho} \tag{7}$$

Where:

Vu = useful volume of the biodigester (m^3);
Q= flow rate;
m= mass of substrate to be digested;
HRT= hydraulic retention time; and,
ρ= substrate density.

- **Débit (Q)**

$$Q = v(1 + x) = \frac{m(1 + x)}{\rho} \tag{8}$$

Where:

Q= flow rate;
x= ratio of water (m^3);
m= mass of substrate;
v= volume occupied by the mass of substrate according to equation (9):

$$v = \frac{m}{\rho} \tag{9}$$

Where:

m = mass of substrate (kg);
ρ = density of substrate (kg/m^3).

- **Total volume of the biodigester (Vt)**

Taking into account the previous, the total volume of the biodigester (Vt) is estimated according to equations (10) and (11).

$$V_t = Q\left[HRT + B_0 S\left(1 - \frac{K}{(HRT \times \mu_m - 1 + K)}\right)\right] \tag{10}$$

Meaning:

$$V_t = \frac{m(1+x)}{\rho}\left[HRT + \frac{B_0 \times C \times \rho}{HRT(1+x)}\left(1 - \frac{K}{(HRT \times \mu_m - 1 + K)}\right)\right] \tag{11}$$

Gwogon's mathematical method

The daily biogas production is obtained from the mass (m) of waste produced per day following relationship 12 (Gwogon, 2013):

$$Daily\ biogas\ production = \frac{m \times P}{100} \times MO \tag{12}$$

Where:

m= mass (t or kg);
P= biogas productivity in (m^3/ton or m^3/kg of organic matter);
OM= organic matter.

P is taken as 390 m^3/t of organic matter and the daily methane production is calculated assuming that the biogas is composed of 60% methane (equation (13)):

$$Daily\ methane\ production = Daily\ biogas\ production \times \frac{60}{100} \tag{13}$$

The biodigester is designed as a cylindrical tank with its bottom as a half-sphere shape. The total volume (m^3) of the biodigester is calculated according to equation (14):

$$\begin{aligned} Total\ volume &= Residence\ time\ of\ the\ substrates \\ &\times Daily\ volume\ of\ the\ substrates \end{aligned} \tag{14}$$

With:

$$Total\ volume = Volume\ of\ the\ Cylyncric\ part + Volume\ of\ the\ hemisphere \tag{15}$$

Amahrouch's mathematical method

Amahrouch (2013) calculates the biodigester volume for dung substrate as follows:

- **Volume of input mixture per day**

The volume of water is added to the volume of substrate.

$$Q = B.F + V_e \tag{16}$$

Where:

Q: volume of input mixture;
BF: volume of the substrate;
Ve: volume of water.

- **Useful volume of the biodigester**

The useful volume of the biodigester is proportional to the volume of the input mixture and the hydraulic retention time.

$$V_u = Q \times HRT \tag{17}$$

Where:
V_u: Volume utile;
HRT: Hydraulic retention time.

- **Potential biogas production**

The potential biogas production (Vb) depends on each substrate's useful volume and specific biogas production (Ps).

$$V_b = V_u \times P_S \tag{18}$$

For cow dung, the specific biogas production is estimated to be $P_S = 0.25 m^3/m^3 biodigester/day$.

- **Total volume of the biodigester**

In the case of a fixed dome biodigester, in addition to the useful volume (Vu) corresponding to the input mixture volume, the biodigester's total volume must account for the volume of biogas potentially produced (Vb).

$$V_t = V_u + V_b \tag{19}$$

Then:

$$V_t = \left(1 + \frac{1}{P_S}\right) V_b \tag{20}$$

$$V_t = (1 + P_S) Q \times HRT \tag{21}$$

Generally speaking, this theoretical volume is sufficient to avoid any risk of overpressure, which could cause an explosion of the installation in extreme cases.

$$\boldsymbol{Q = \frac{V_t}{(1 + P_S) \times HRT}} \tag{\textbf{22}}$$

Estimation of biogas and methane production by the empirical method

Several authors have developed empirical methods for estimating the biogas produced based on laboratory experiments. The abacus according to Norosoa (2016) was used to determine the biogas production. For HRT = 60 days, T= 250 °C, and 1 kg of dung, the volume of biogas was estimated to be 34 L or 0.034 m^3. Therefore, with a mass m (kg) of dung per day (Table 2), we expect the daily biogas production (Vb) according to equation (23).

$$\mathrm{V_b = m \times 0{,}034 m^3} \tag{23}$$

ISSN: 1857-7881 (Print) e - ISSN 1857-7431

Table 2. Dung production at the Port-Bouët slaughterhouse from 2013 to 2018.

Year	2013	2014	2015	2016	2017	2018
Dung (kg/d)	10788.64	12564.66	13066.24	16593.06	18567.82	17665.61

Ecological Footprint Assessment

Amount of greenhouse gases avoided

The approach consisted in estimating the amount (Qi) of greenhouse gases (CH_4 + CO_2) contained in the biogas produced before energy recovery by combustion, then calculate the amount (Qd) of CO_2 released during biogas combustion. The amount of the avoided greenhouse gas (Qe) was obtained by taking the difference between Qi and Qd (Kadjo, 2018).

Amount (Qi) of greenhouse gas from biogas

In this section, the amount of CH_4 contained in the biogas produced was estimated because gas emissions in the form of CO_2 related to organic substrates are not considered GHG emissions because they are part of a short cycle, unlike CO_2 emissions related to fossil energy use. After evaluating the amount of biogas produced and determining the volume percentage of methane, the amount of greenhouse gases from the biogas is estimated.

According to ADEME (2009), the calculation of the methane emissions to elaborate the greenhouse gas balance is realized according to equation (24):

$$CH_4\left(k_g\,CO_2e\right) = Q_i = MB \times Methanogenic\ Potential \times FE \times conversion\ factor \quad (24)$$

Where:

MB = raw material (kg);
EF = emission factor taken at 78%;
methanogenic potential (m^3 CH_4 /kg MB); and,
Conversion factor of CH_4 to CO_2 equivalent = 25 gCO_2/gCH_4 (IPCC, 2007).

Quantity (Qd) of CO_2 released during biogas combustion

The amount (Qd) of CO_2 released during biogas combustion was determined according to equations 25 and 26.

- ✓ Biogas combustion (CH_4 + CO_2):

Let X and Y be the molar proportions of CH_4 and CO_2 contained in the biogas to be burned.

$$(XCH_4 + YCO_2) + (2X)(O_2 + 3.76N_2) \rightarrow (X + Y)CO_2 + (2X)H_2O + (2X.3.76)N_2$$

- ✓ Methane combustion:

Methane is the only component of biogas with a calorific value, unlike carbon dioxide (CO_2) and nitrogen (N_2). Therefore, methane combustion is described as follows:

$$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$$

$$1mole(CH_4) \rightarrow 1mole(CO_2)$$

$$n(CH_4) = \frac{V_{CH_4}}{V_m}$$

where:

V_{CH_4}=volume of methane in the biogas (L);

$V_m = 22.4L/mol.$

Note that:

$$V_{CH_4}(L) = V_{biogaz}(L) \times \%CH_4 \tag{25}$$

Thus,

$$n = \frac{V_{biogas} \times \%CH_4}{22.4} \tag{26}$$

This leads to:

$$n_{CH_4} = n_{CO_2} = \frac{V_{biogas} \times \%CH_4}{22.4} \tag{27}$$

$$m_{CO_2} = n_{CO_2} \times M_{CO_2} = \frac{V_{biogas} \times \%CH_4 \times 44}{22.4} \tag{28}$$

With:

$$M_{CO_2} = \frac{44g}{mol} \tag{29}$$

Where: M_{CO_2}= the molar mass of carbon dioxide

$$Q_d(g) = m_{CO_2}(g) = 1964 \times V_{biogas}(litre) \times \%CH_4 \tag{30}$$

$$Q_d(g) = m_{CO_2}(g) = 1964 \times V_{biogas}(m^3) \times \%CH_4 \tag{31}$$

Finally, the amount of GHG avoided (Qe) by the valorization of biogas produced from the dung was estimated by equation (32):

$$Q_e = Q_i - Q_d \tag{32}$$

Where:

Qe= Amount of greenhouse gases avoided;
Qi= Amount of greenhouse gases from biogas;
Qd= Amount of CO_2 released during the combustion of the biogas.

Results and discussion

Designing of the biodigester and assessment of biogas and methane production by mathematical methods

Mathematical method of Hashimoto

Hashimoto's method shows in Figure 1 the evolution of the daily biogas and methane production according to the biodigester volume over six years. A correlation was observed between the biodigester volume, and the amount of biogas and methane produced. Indeed, biogas and methane production increases with biodigester volume regardless of the year. The biogas occupies about less than 1/5 of the biodigester volume. On the other hand, an increase in the amount of biogas was observed from 2013 (328 m^3 to 564.50 m^3) to 2017 (1622.63 m^3 and 2792.64 m^3). For methane production, the volume produced was 196.80 m^3 in 2013 and 338.70 m^3 in 2017. In 2018, there was a decrease in biogas production (537.07 m^3) and methane as well (322.24 m^3).

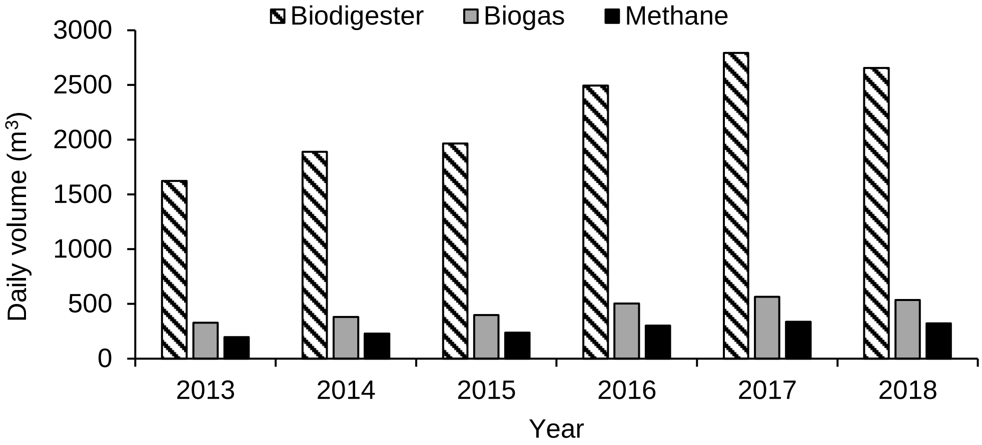

Figure 1. Evolution of the daily biogas and methane production according to the volume of the biodigester by the Hashimoto method

Gwogon's mathematical method

The evolution profiles of the daily production of biogas and methane and the biodigester volume according to the Gwogon method are shown in Figure 2. Overall, the daily production of biogas and methane and the biodigester volume gradually increased from 2013 until 2017. However, there was a decrease in 2018. The biodigester with the lowest volume (1294.64 m^3) in 2013 recorded the lowest volumes of biogas (420.76 m^3) and methane (252.45 m3). On the other hand, in 2017, the biodigester of a larger volume (2228.14 m^3) produced 724.15 m^3 and 434.49 m^3 of biogas and methane, respectively, that is, the highest production of biogas and methane

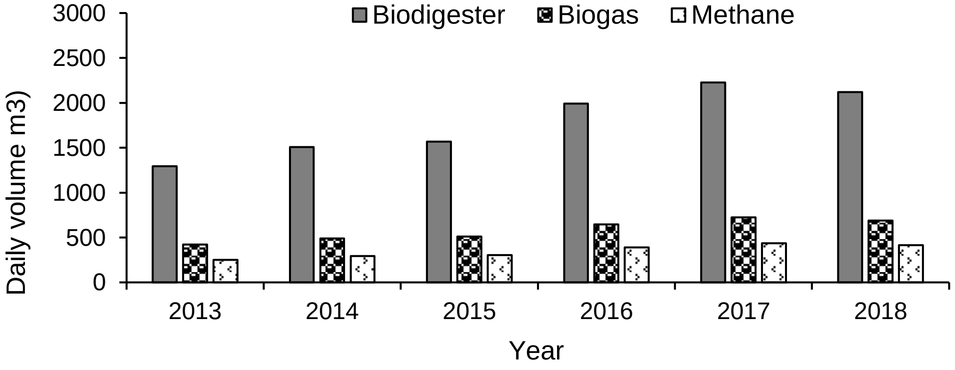

Figure 2. Evolution of the daily biogas and methane production according to the volume of the biodigester by the Gwogon method

Amahrouch mathematical method

Figure 3 shows the daily amounts of biogas and methane produced from 2013 to 2018 and the corresponding biodigester volume according to the mathematical calculations of Amahrouch. The daily biogas and methane production increased until 2017 but decreased slightly in 2018. This production was minimal in 2013, with 323.66 m^3 of biogas and 194.20 m^3 of methane. On the other hand, this production reached a maximum in 2017 with 557.03 m3 of biogas and 334.22 m^3 of methane. The biodigesters that recorded these values in 2013 and 2017 have volumes of 1618.30 and 2785.17 m^3, respectively.

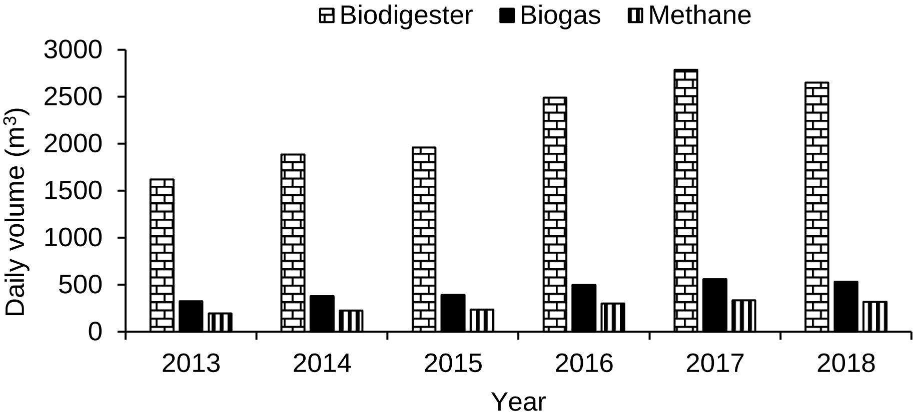

Figure 3. Evolution of the daily biogas and methane production according to the volume of the biodigester by the Amahrouch method

Estimation of biogas and methane production by the empirical method

Figure 4 shows the evolution of daily biogas and methane production per year according to the empirical method. This production increased from 2013 to 2017, then decreased in 2018. The maximum volume of biogas (631.31 m^3) and methane (378.78 m^3) was recorded in 2017, while the minimum volumes of biogas (366.81 m^3) and methane (220.09 m^3) appeared in 2013.

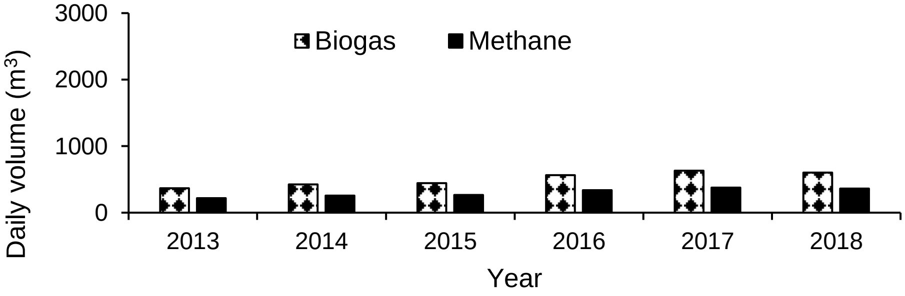

Figure 4. Evolution of the daily biogas and methane production from 2013 to 2018 according to the empirical model

Comparison between mathematical methods and the empirical method

It should be noted that methods are different from each other. The empirical method showed biogas volume values higher than those calculated by Hashimoto and Amahrouch. Indeed, in 2017, biogas production was 631.31 m^3/d, 557.03 m^3/d, and 564.50 m^3/d for the empirical, Hashimoto, and Amahrouch methods, respectively. The highest volume of biogas produced (724.15 m^3/d) was estimated by Gwogon's model.

The relative uncertainty was evaluated based on the 2017 highest biogas production.

- Relative uncertainty between the Hashimoto model and the empirical model:

$$\nabla_{Pv}= \frac{|564{,}50 - 631{,}31|}{100} = 0{,}6681\, m^3$$

- Relative uncertainty between the Gwogon model and the empirical model:

$$\nabla_{Pv}= \frac{|724{,}15 - 631{,}31|}{100} = 0{,}9284\, m^3$$

- Relative uncertainty between the Amahrouch model and the empirical model:

$$\nabla_{Pv}= \frac{|557{,}03 - 631{,}31|}{100} = 0{,}7428\, m^3$$

The uncertainty values between the models are not such as to call into question the results obtained from these models.

The Hashimoto model had the lowest uncertainty value compared with the empirical model, whereas the Gwogon model recorded the highest relative uncertainty.

Evaluation of the Ecological Footprint with mathematical methods

Figure 5 plots the amounts of CO_2 avoided per kilogram of dung according to the mathematical methods of Hashimoto, Gwogon, and Amahrouch from 2013 to 2018. From 2013 to 2018, the amounts of CO_2 avoided per year were roughly the same for each method regardless of the individual year. Indeed, the amounts of CO_2 avoided are as follows: Gwogon's method (41579.88 to 71561.17 kg CO_{2e}), Hashimoto's method (41689.19 to

71749.30 kg CO_{2e}), and Amahrouch's method (41694.30 to 71758.10 kg CO_{2e}).

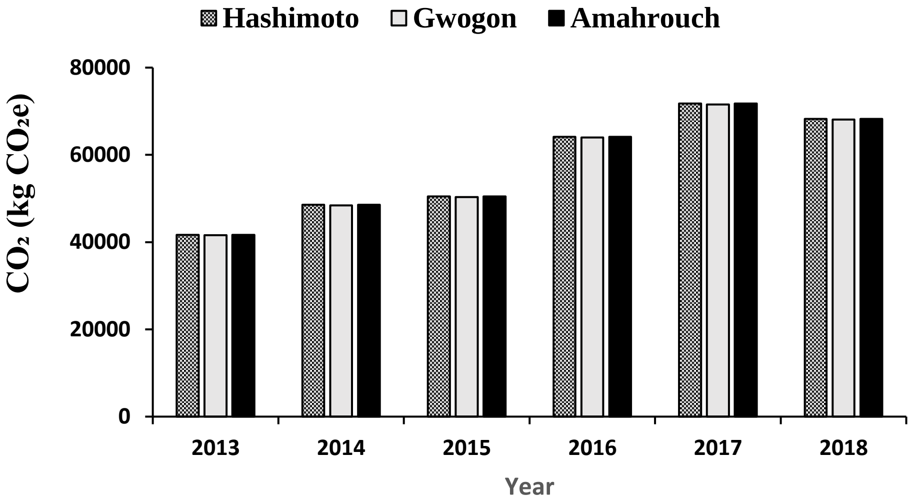

Figure 5. Greenhouse gases avoided per kilogram of dung from 2013 to 2018 following the mathematical methods of Hashimoto, Gwogon, and Amahrouch

Evaluation of the Ecological Footprint with the Empirical Method

Figure 6 shows the amount of gas avoided from 2013 to 2018 using the empirical model. Results show that managing waste such as cow dung at the slaughterhouse of Port-Bouët through the production and valorization of biogas could avoid 41,643.46 to 71,670.58 kg of CO_2e from 2013 to 2018.

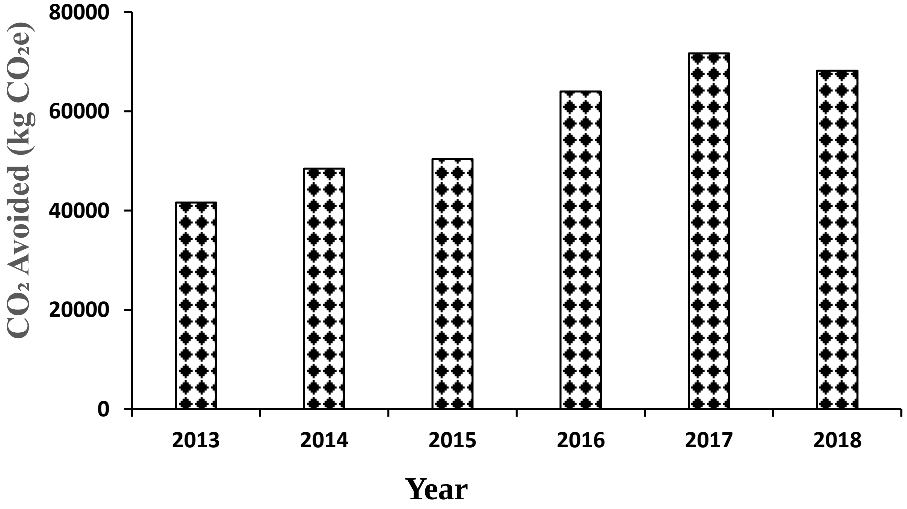

Figure 6. Amounts of gas avoided gas from 2013 to 2018 according to the empirical model

Discussion

This study assessed the GHG mitigation potential of a biodigester for dung waste treatment at the slaughterhouse of Port-Bouët. More specifically, the daily biogas production from 2013 to 2018 was estimated using the mathematical methods of Hashimoto, Gwogon, and Amahrouch and an empirical method to estimate the amount of CO_2 avoided per kilogram of dung.

Based on the results, the highest daily biogas production was obtained in 2017 for all methods. This could be due to the increase in dung production since 2013, reaching a peak in 2017.. For instance, wste production was 16593.06 kg/d in 2016 and grew to 18567.82 kg/d in 2017. Thus, biogas production evolves with waste production. Indeed, biogas production depends on the amount and quality of the substrate. This quality is essentially considered through its percentage of methane (CH_4). Indeed, the higher the percentage of methane, the better the biogas quality (Akrout, 1992).

By comparing the daily quantities of biogas produced according to the various methods, one notices that the methods of Hashimoto and Amahrouch give approximately the same results, i.e., similar amountsof biogas produced. On the other hand, with Gwogon’s approach, one obtains quantities of biogas higher than those of Hashimoto and Amahrouch. For the empirical method, biogas quantities are higher than those determined by Hashimoto and Amahrouch methods. However, these quantities are lower than those estimated with Gwogon's method.

These results would be explained by the various parameters influencing biogas production (Sawyerr et al., 2019). Indeed, these parameters can slow down or block the biogas production process if their values are outside the required range (Angelidaki et al., 2009).

The main parameters were hydraulic retention time (HRT), substrate pH, nutrients, feed rate, amount of substrate to feed the biodigester, fermentation temperature, agitation quality, residence time, volatile fatty acids, and free ammonia concentration (Tchouate Héteu and Martin, 2003; Sawyerr et al., 2019). It should be added that the number of these parameters considered in the different methods applied in the present study differ.

Moreover, the biodigester total volume results, estimated with both Hashimoto and Amahrouch models, were quite similar. This could be explained by the fact that the calculation of this volume with both methods is a function of the biodigester's useful volume and biogas volume (Norosoa, 2016).

In the Gwogon model, the volume of the biodigester was obtained as a function of the hydraulic retention time and the substrate volume used.

These different values are substantially in the same order of magnitude and considerably show that the quantities of greenhouse gases that emanated into the atmosphere during these six years are synonymous with intense activity in the said slaughterhouse. And this activity is set to intensify further. The optimized management of this waste would improve the atmosphere's quality by reducing high methane emissions. Thus, choosing the anaerobic digestion process could be a continuous digester of the mixed type where the substrate is introduced daily with liquid. Currently, steady digestion is the most demanded and the most developed in the anaerobic sector since it has the following characteristics:

- Treatment of a substrate that does not exceed 15% dry matter (DM) in the digester.
- Has a single tank.
- Daily introduction of the substrate into the biodigester, thus allowing regular gas production..
- Ease of work when loading and emptying the substrate. The continuous system consisted of a reactor where the methanation was produced and a gasometer (gas tank) to store the gas..

Furthermore, it would be relevant to (i) make a mixture of waste (dung, litter, grease, wastewater loaded with blood) to have the best possible yields of biogas and (ii) reduce the environmental impacts of waste, including health and greenhouse gas mitigation.

Conclusion

This study aimed to evaluate the potential of a biodigester to mitigate GHG emissions. It showed that the methanization of the putrescible organic residues is a viable solution for the sustainable management of abattoirs' waste. Indeed, the mathematical methods of Hashimoto, Gwogon, and Amahrouch and the empirical approach were suitable for estimating the quantities of biogas produced and the CO_2 equivalent avoided per kilogram of dung. This shows that the methanization of cow dung waste has a positive impact on the environment since the capture of biogas makes it possible to limit the release of methane, a greenhouse gas, into the atmosphere, thus contributing to the fight against global warming. Therefore, implementing a biodigester plant at the abattoir of Port-Bouët in the District of Abidjan could help Côte d'Ivoire achieve its climate commitments as in the NDC under the Paris Agreement on climate.

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