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Estimation of Methane Emission from a Waste Dome in a Tropical Insular Area

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Abstract

In the Caribbean, most of the waste is stored in open landfills without biogas collection systems. Methane emission from landfills is a major contributor to Greenhouse effect. Several models projecting methane emissions from landfills have been proposed in literature. The Landfill Gas Emissions Model (LandGEM) is one the conventional models allowing to take into account, though roughly, the climate environment. By comparing model results with field measurements in previous works, the LandGEM gave good results. Most of the studies using the LandGEM were principally conducted in the United States or in Europe.

Few studies have made use of LandGEM in tropical areas. Caribbean islands are characterized by significant rainfall and high humidity throughout the year. In this study, we apply the LandGEM to La Gabarre, the main open landfill of Guadeloupe archipelago in the Lesser Antilles. By comparing model results to field measurements, we observe that the model biogas production is greater than recovered biogas collected to be flared by a factor of 1.94. However, accounting for numerous error factors such as a recovery efficiency of the collection system which is necessarily lower than 100%, waste coverage type or the fact that LandGEM model assumes that all waste is household waste, this bias remains acceptable. For the same amount of stored waste, the methane production calculated by LandGEM model will be 4 times higher in Guadeloupe than in drier areas.

Keywords: Landfill; Waste dome; Emission; LandGEM; Methane; Tropical area; Biogas flare system

Introduction

In Guadeloupe archipelago, landfilling is the preferred method for managing waste [1]. Landfilling is the process in which waste products are compacted and disposed of into a landfill [2]. Landfill sites containing wastes undergoing biological decay, specifically in an advanced methanogen stage of decomposition, typically emit high volumes of landfill gas [3]. Main landfill gas components are methane (CH_4) and carbon dioxide (CO_2) with percentage shares ranging from 40 to 60% [4].

Methane emission from landfills caused by degradation of organic matter is a major contributor to the greenhouse effect [5]. Methane is regarded as one of the most important greenhouse gases (GHG) because its global warming potential has been estimated to be more than 20 times greater than carbon dioxide's one. Atmospheric methane concentration has been increasing in the range of 1-2% per year [6]. The waste sector is a significant contributor to GHG emissions, accountable for approximately 5% of the global greenhouse budget [7].

These last years, efforts have been made to control GHG emissions from waste sector. Reducing the GHG emissions contributes to stabilizing GHG concentrations in the atmosphere at a level that would prevent the dangerous anthropogenic interference with the climate system [8]. According to the Kyoto protocol, GHG emissions for each nation should be reported annually. The 2006 IPCC Guidelines for National Greenhouse Gas inventories provides detailed guidelines on how annual GHG emissions from landfills can be estimated [7]. European Union member countries, including France, have adopted a specific Protocol on Pollutant Release and Transfer Registers (PRTR). The annual methane emissions statutorily reported by landfill operators are documented in the European Pollutant Release and Transfer Register (E-PRTR) established to implement the PRTR Protocol. Moreover, reporting methane emissions is interesting for an additional reason since it is also a way of assessing the possibility of recovering landfill gas (LFG) as an alternative energy source.

Landfills are not point sources but diffusive sources of methane [9]. Therefore, it is not easy to measure methane emission due to its high temporal and spatial variability [10]. Model-approaches present advantages in terms of lower cost and provide relatively quick results. Landfill gas models usually describe the complex changes occurring during landfill decomposition to estimate methane generation over time. Models are often used for sizing landfill gas collection systems, evaluation and projection of LFG energy uses, and regulatory purposes as required by the international protocols mentioned earlier [11]. Several models predicting methane emissions originating from landfills have been proposed in literature. Many of them are simple first-order decay models which do not require to have a too detailed knowledge of the waste composition. For example, in studies conducted by Paraskaki and Lazaridis [12] and Chalvatzaki and Lazaridis [8], three different landfill gas emission models were used in Greece: the triangular model, the stoichiometric model and a first-order model the Landill Gas Emissions Model (LandGEM). After comparing the measurements in the field with the output of 3 models, the LandGEM presented the best results. Other models such as IPCC-model, the TNO-model and GasSim will produce reasonable results from municipal solid waste dominated by household waste, landfilled in northwestern Europe in humid oceanic climate. However, the accuracy of some of these models for other climate zones is questionable [13]. Though to a very limited extent, LandGEM model takes into consideration the rainfall variability observed with climate zone changing. As a result, at least one of the tropical climate component should be integrated in the model calculation. Another example is the Ryerson Landfill Gas Model (RLGM) developed using the IPCC model. After comparing the RLFGM and LandGEM outputs, it was found that RLFGM was producing similar type of output graph as the LandGEM. Nevertheless, the rate of methane emission into the environment is lower in RLFGM model [14]. All these models were mainly applied in Europe or in the US and few data exist for Caribbean area. Model data with a field validation from this area and other sources should allow a better evaluation of the models accuracy in other regions than Europe and US. On the other hand, managing waste and controlling energy are real issues in island regions. To properly model landfill methane emissions for hot tropical climates would be a useful tool for policy makers of the insular Caribbean regions.

Among the traditional models frequently referenced in the literature, the LandGEM has interesting advantages for our study: good agreement with field measurements and the possibility, though rough, to take into account the landfill location in a tropical area. The aim of this study is to compare LandGEM model to field measurements for biogas production in a tropical environment. So, we have applied the LandGEM emission model to assess methane landfill emission in Guadeloupe. Only La Gabarre landfill, the biggest open landfill of the archipelago, is equipped with an effective biogas recovering system. Nevertheless, other smaller and no longer operated open landfill sites can be found in some places of the archipelago. In a close future, it will be necessary to make policy decisions concerning their rehabilitation and valorization. Modelling could provide an approximate idea of these landfills long-term energetic potential and should also enable to properly size the recovery systems to put into operation.

Materials and Methods

Description of la Gabarre landfill site

In Guadeloupe (at the North of the Lesser Antilles, French West Indies, island tropical and humid climate), La Gabarre is the main open landfill. It is located in a mangrove area that surrounds it. Opened in 1973 with an initial area of 5 ha, it reached 37 ha in 2015. For over three decades (from its opening until 2010), all types of waste were stocked at La Gabarre.

In 2015, this landfill was composed of 3 parts: uncovered fresh waste (less than one month of deposit), uncovered old waste (at least 6 months of deposit) and covered waste (stored waste for more than 20 years in the waste dome rehabilitated area). This last part (rehabilitated waste dome) has been operated for waste disposal from mid-90 to the end of January 2013. Throughout the rehabilitation, wells have been installed to collect gas and drainage systems to collect leachate. The fresh waste part (active cell) is operated since February 2013 which is foreseen to last until 2016.

The LandGEM has been applied to the area of the landfill corresponding to the rehabilitated dome. This software estimates the emissions resulting from the biodegradation of waste in landfills for anaerobic decomposition [15]. In this location, the waste was spread out over the ground as a layer, then it was compacted to decrease its volume, and finally it was covered with a tufa layer. The “waste plus tufa” stacking was repeated several times which explains the waste dome formation over time. At the last stage of the process, the pile was topped with a layer of topsoil. The rehabilitated waste dome reached an area of 12 ha and a height of 24 m. Fifty draining wells with a depth of 15 m have been installed on the dome for collecting the biogas. During its active period, this part received up to 600 tons of waste per day. The waste in the dome was principally composed of household waste (~52%), bulky refuse (~20%), green waste (~11%) and packaging (such as plastic, wood, carton, etc) (~10%).

Landfill gas emissions model (LandGEM)

Description: The Landfill Gas Emissions Model is a modelling tool for quantifying uncontrolled emissions of various compounds present in the landfill gas over a time period, from municipal solid waste landfills [12]. It is developed by the Control Technology Center of the American Environmental Protection Agency (US EPA). The model determines the mass of methane generated using the methane generation capacity and the mass of waste deposited. LandGEM is based on a first-order decomposition rate equation given below by (1) [15].

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{10} kL_0 \left(\frac{M_i}{10}\right)\left(e^{-kt_{i,j}}\right) \quad (1)$$

Where Q_{CH4} is the annual methane generation in the year of calculation (m^3/year), i the yearly time increment, n is the difference (year of the calculation) − (initial year of waste acceptance), j the 0.1 year time increment, k is the methane generation constant (year^{-1}), L_0 is the potential methane generation capacity (m^3/Mg), M_i is the mass of waste in the ith year (Mg) and $t_{i,j}$ is the age of the jth section of waste M_i accepted in the ith year (decimal years).

To conduct our study, the required inputs for estimating the amount of generated landfill gas are the landfill opening year, the landfill closure year, the annual waste acceptance rates from the opening to the closure year, the methane generation constant k, the potential methane generation capacity L_o, NonMethane Organic Compound (NMOC) concentration and methane proportion in the biogas.

Model inputs

Opening and closure of the dome: The disposal of waste having built the dome we study here, started in the 90 s but no more accurate date could be identified. We have chosen the mid-90 s as the date of initiation of the dome. The last disposal of waste on this dome was in January 2013. To run this model, we decided to take 1995 as landfill opening year and 2012 as closure year.

Annual waste acceptance rates: The yearly waste tonnage is a crucial LandGEM model setting. The weighing of waste at the landfill entrance only started in 1998 [16]. These data have been partly archived and could only be obtained for 2002 and 2003 (personal communication of the landfill operator) in our previous study [17] and from 2008 based on Guadeloupe SICTOM (Syndicat Intercommunal de Traitement des Ordures Ménagères or the Intercommunal household waste treatment Syndicate which operates the landfill) annual activity reports [18,19]. For missing years (from 1995 to 2001 and from 2005 to 2007), waste tonnages have been estimated assuming that, during the studied period, for a given number of municipalities dumping their solid waste in the landfill, the waste annual tonnage to the municipalities total population ratio is roughly constant from one year to another. This ratio is calculated for those years for which waste annual tonnage is available and is then applied to the other years. To complete this calculation, we have used the census population count provided by the French National Institute of Statistics and Information about the Economy (INSEE). As a result, the estimated annual tonnage remains quite stable around 60000-70000 tons from 1995 to 2006 with a number of four municipalities and an annual tonnage to population ratio from 1995 to 2001 and 2004 to 2006 being calculated by averaging 2002 and 2003 values. 2007 ratio is found through linear fit of the ratio values as a function of population values, leading to an annual tonnage of about 120000 tons. For the last five years of the dome operation, from 2008 to 2012, the annual tonnages are available from the landfill operator annual activity reports and do not need to be estimated. From 2008 to 2010 with 11 municipalities, the annual tonnage is roughly 210000-220000 tons. In 2011 and 2012; despite of a greater number of municipalities (19 in 2012) and thanks to a better waste upstream separation and an extension of selective sorting to new materials with the emergence of new recycling facilities, the annual tonnage does not increase [20]. In 2012, the annual tonnage is even lower than 2008's one. All information described above are listed in Table 1.

Year	**1995-2001**	**2002**	**2003**	**2004-2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Number of municipalities	4	4	4	4	6	11	11	11	15	19
Ratio (waste tons per inhabitant)	0.47	0.43	0.52	0.47	0.68	0.91	0.97	0.91	0.86	0.70
Waste annual tonnage	62898	56439	69478	63008	120503	214736	227423	214177	226210	194676

Table 1: Evolution of the waste annual tonnage between 1995 and 2012.

Methane generation constant k: Default values for k can be used or site-specific values can be introduced using the equation (2) [21].

$$k = 3.2 \times 10^{-5}(annual\ \ mean\ \ rainfall) + 0.01 \quad (2)$$

With the annual mean rainfall being determined from meteorological data collected in the study area. Indeed, 2 km from the landfill, we find the Météo France station providing rainfall data. Between 1971 and 2000, Météo France measure an annual mean rainfall of 1628 mm [22]. Over the last decade rainfall has not drastically changed in Guadeloupe. Therefore, in our case k has been estimated by the equation (3).

$$k = 3.2 \times 10^{-5}(1628) + 0.01 = 0.06\ \ year^{-1} \quad (3)$$

Potential methane generation capacity L_o: The potential methane generation capacity Lo depends mainly on the nature of waste disposed in the landfill. The Lo value will be greater for waste containing a lot of cellulose. The five Lo values given for household waste are presented in Table 2.

Emission type	**Landfill type**	**L0 Value (m^3/Mg)**
Clean Air Act	Conventional	170 (default)
Clean Air Act	Arid Area	170
Inventory	Conventional	100
Inventory	Arid Area	100
Inventory	Wet (Bioreactor)	96

Table 2: Values for the potential methane generation capacity (US EPA, 2005).

Clean Air Act default parameters in LandGEM parameterization means that emission type is based on requirements for MSW landfills laid out by the Clean Air Act. Inventory default parameters are based on emission factors in the U.S. Environmental Protection Agency's (EPA's) Compilation of Air Pollutant Emission Factors [15].

According to studies conducted by the US EPA on 21 different landfills in the US, the appropriate Lo value for most of the landfills is 100 m^3/mg [23]. This value has been chosen for this work because it presents the best results between emissions from empirical data (measured) and projected emissions according to US EPA [24].

Nonmethane organic compound (NMOC) concentration: The concentration of NMOC varies with the type of waste. Applying the default values of the model, it can be 600 ppmv for landfills containing only household waste and 2400 ppmv for those receiving both household waste and other types of waste [23]. Up until 2008, La Gabarre landfill received all types of waste so we have chosen a NMOC concentration of 2400 ppmv.

Methane proportion: The methane proportion in the biogas was measured in the framework of measurement campaigns carried out during the landfill rehabilitation operation, on 40 wells installed to collect the biogas, with the Mutitec 540 of SEWERIN a multiple gas measuring device with infrared sensors optimized for biogas and landfill gas [17]. This equipment can measure six gases simultaneously but the use of infrared measuring techniques for methane and carbon dioxide means that there is no possibility of misleading results due to interaction with other gases whose measurement makes use of electro-chemical sensors. In less than 5 minutes, results are displayed on the equipment's screen and are stored in the device. At La Gabarre landfill, the infrared sensor of the Multitec was placed directly in the manhole of each well. Average proportion values of 58.5% for CH_4 and 41% for CO_2 were measured. These percentages are very close to the average values found in the literature during the methanogenesis in anaerobic fermentations: 60% CH_4 and 40% CO_2 [4]. For running the model, we chose to keep a biogas consisting of 60% CH_4 as suggested in previous studies.

Biogas data from field measurements: There are different systems for biogas treatment. For the rehabilitated dome in this landfill, the operator has chosen the recovering followed by a complete destruction of the biogas by combustion (thermal oxidation of methane in a flare), because of the end of the dome operation leading to a decline of the biogas production and a decrease of the methane content below the level necessary to constitute an alternative energy source. In the gas

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collection system, the biogas is captured by draining wells of a depth of 15 m. The network of 50 extraction wells is connected to a high temperature biogas flare system designed and built by the company BIOME. The system includes a booster which creates a negative suction pressure of -100 mbar to pull the landfill gas collected in the waste dome towards an enclosed flare. The enclosed flare used at La Gabarre is a BIOME BBC 300–1800 m^3/h (it can burn between 300 and 1800 cubic meters of methane per hour at a temperature of about 900°C). Its frame weighs 3.5 tons, has a diameter of 2 m and a height of 8 m. The enclosed flare is capable of flaring biogas with methane rate between 20 and 70%.

The biogas flare system has a control panel to operate the flare, display and record the data. The flare system is also measuring the biogas flow with the aid of a Pitot tube flow meter and the gas concentration with a biogas analyzer. Data are recorded each hour to control the flow and quality of the biogas produced by the waste dome.

Results and Discussion

LandGEM results at la gabarre

Figure 1 exhibits the annual landfill gas production rates provided by the LandGEM for the rehabilitated waste dome of La Gabarre.

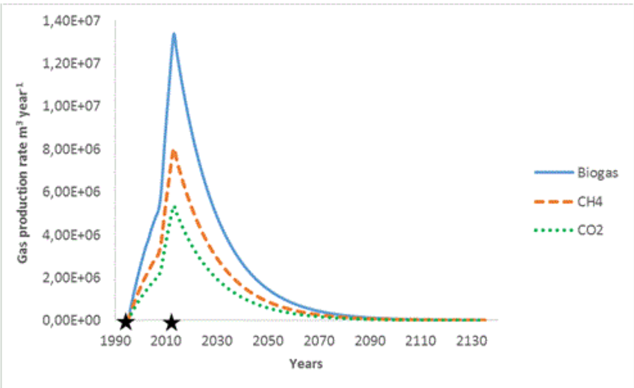

Figure 1: Annual landfill gas production rates (m^3 $year^{-1}$) provided by the LandGEM model at La Gabarre for a rehabilitated waste dome in activity between 1995 and 2012 (black stars).

The first year of waste deposit (considered as the first year of the rehabilitated dome building), the model assumes that there is no biogas production. Indeed, in the literature, it is stated that the methanogenesis step starts at least 6 months after tipping of waste. Waste degradation depends on many factors: type of waste, moisture in the waste, climatic conditions, material which covers the waste, etc. To simplify the computations, the LandGEM does not take into account all these parameters to establish the beginning of methanogenesis and considers that after a year, all criteria are met for the start of this step.

According to the model outputs, the dome has produced 5.88×10^5 m^3 $year^{-1}$ of biogas in 1996 including 3.53×10^5 m^3 $year^{-1}$ of CH_4 and 2.35×10^5 m^3 $year^{-1}$ of CO_2. Over the years, the production of biogas would grow until 2013 when we record the maximum biogas production rate with 1.34×10^7 m^3 $year^{-1}$. As observed in all studies using this model, the maximum production takes place one year after the closure of the landfill (in our case after the end of the dome operation). If the collection system had been operational that year, the operator would have collected 8.13×10^6 m^3 $year^{-1}$ of CH_4. In terms of health and security, such values indicate that operations in La Gabarre landfill during 2013 year should have presented a significant risk for the employees on the site [25].

After 2013, the production of biogas should decrease drastically and reach its lowest value in 2135: 8.87×10^3 m^3 $year^{-1}$. This rapid decrease in biogas production is explained by the fact that there are fewer and fewer waste to degrade. However, 123 years after its end of operation, the dome should always produce 5.32×10^3 m^3 $year^{-1}$ of CH_4.

Figure 2 illustrates the cumulative amount of methane produced by the waste dome.

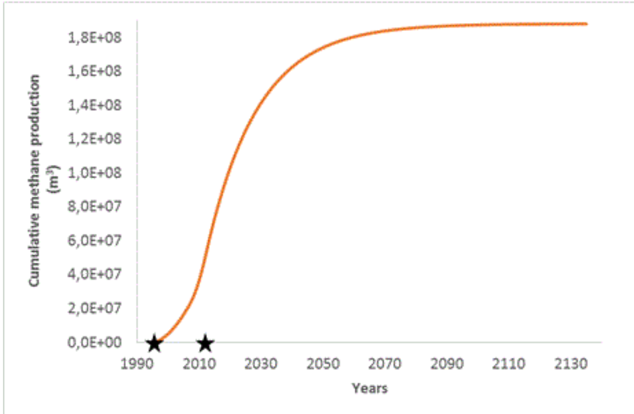

Figure 2: The cumulative amount of methane produced by the rehabilitated waste dome opened in 1995 and closed in 2012 (black stars) with LandGEM data.

According to LandGEM, the dome should have produced between 1995 and 2135 no less than 1.8×10^8 m^3 of CH_4.

Comparison of landGEM data with field measurements

To compare LandGEM data with field measurements, we have chosen the 2014 year. For the first 6 months of this year, we have the monthly mean flow of biogas given by the landfill operator. For the period going from January to June 2014 which corresponds to the dry season in Guadeloupe, we have a mean biogas flow of 555 ± 48 m^3 $hour^{-1}$ with a mean rate of 36 ± 4% of CH_4. These values are obtained for three-quarters of the opened wells. Assuming that all wells were opened, we obtain by extrapolating a mean flow of biogas of 740 m^3/h.

For 2014, LandGEM has found a yearly biogas production of 1.261 × 10^7 m^3 with 60% of CH_4. After converting this data in an hourly value, we obtain a mean hourly flow of 1439 m^3/h. We must recall that the model provides information on the biogas that may be generated by a given amount of waste while field measurements provide the biogas volume recovered in the flare system. The difference between both values depends on the recovery efficiency of the recovering system which can experiment great variations between 25 and 75% according to previous studies [13]. This could also be one of the explanations of the notable discrepancy between the model (60%) and the extrapolated from field measurement (36%) methane rates. The model could suggest a biogas quality better than it actually is if recovery efficiency is not accounted for.

We can now compare the two biogas hourly flow values with the equation (4).

$$r = \frac{Q_{LandGEM}}{Q_{Measurements}} = \frac{1439}{740} = 1.94 \qquad (4)$$

With:

$Q_{LandGEM}$ (m^3/h): mean flow of biogas deduced from LandGEM

$Q_{Measurements}$ (m^3/h): mean flow of biogas extrapolated from field measurements

The ratio between the model and the measurement is 1.94. Following this result, we could predict a recovery efficiency of the collection system of about 52%. There are several factors leading to defaults of the collection system that could explain this value.

To begin with, we have no guarantee that all of the biogas produced is captured by the wells.

Methane generation is possible only for strict anaerobic conditions. During its rehabilitation, the waste dome has undergone many transformations which can have had a significant impact on the anaerobic conditions. The various transformations could have unsettled the anaerobic system. Air can be introduced in the dome because of gas pumping, changes in the relative pressure within the landfill, or deterioration of the collection system [13,26]. Moreover, the production rate depends on the density of compaction and on the greater or lesser porosity of the cover. In addition, during drilling of the waste dome for wells network installation, gas pockets could have been broken causing a loss of gas [17].

Other sources of error may find their origin in the approximations made by the model:

The L_0 used in this study is a default value derived from previous works on many US landfills. We are not sure that this value is representative of our site. When applying a L_0 of 96 m^3/mg, the results remain almost unchanged (but this L_0 value is very close to the 100 m^3/mg used here to run the model). On the other hand for L_0 = 70 m^3/mg, the final biogas production flow would be 1.7 times higher. Conclusions made after comparing L_0 values used by different models clearly show that LandGEM value is at least twice the other models values. The long term tendency should be an overestimate of emissions by LandGEM [13].

The software does not make any difference between wastes of different compositions. It considers that all waste is household waste which represents a strong biodegradable fraction and this causes the model to overestimate biogas production [9].

The model does not take into account waste coverage type. Many studies show the importance of the nature of the material covering the waste for the production and emission of methane [27]. Depending on the nature of the soil, the methane can undergo a microbial oxidation which reduces its emission. The microorganisms responsible for this oxidation are mainly methanotrophic microorganisms [28].

The tufa covering the waste can have a significant impact on the growth of microorganisms which are active during waste degradation. Elsewhere, waste is covered with topsoil. In this latter case, the pH is neutral and favorable to the microorganisms responsible for anaerobic fermentation [29]. But if the waste is covered with tufa (calcium carbonate), the pH of the medium at the start of reaction is strongly basic and can inhibit the growth of these microorganisms [30].

In addition to the limitations due to the collection system or model configuration, there is also an uncertainty associated to our calculation of biogas flow measurement. To obtain the biogas flow for all the waste dome, we have assumed that all wells were emitting in the same way and this may not be the case. The location of the wells can have a strong influence because the age and the type of the waste is not the same everywhere.

In conclusion the ratio 1.94 does not seem absurd if considering all the arguments above. By comparison with other works found in the literature, we can even say that La Gabarre is an interesting case because of its tufa cover. Chosen for its wide availability in Guadeloupe and its lower cost compared with topsoil, this material limits biogas emissions and the landfill biogas productivity.

LandGEM data for la gabarre compared to other studies

Table 3 summarizes the main input data and results obtained with LandGEM 3.02 for different sites.

	La Gabarre	**Akrotiri (A)**	**Akrotiri (B)**	**Kahrizak**
Location	Guadeloupe	Greece	Greece	Iran
Open year	1995	2003	2007	1992
Closure year	2012	2007	2013	2004
Total amount of waste (Tons)	20×10^5	44×10^4	66×10^4	21×10^6
Type of Climate	Tropical humid	Arid	Arid	Arid
k ($year^{-1}$)	0.06	0.02	0.02	0.05
L_0 (m^3/Mg)	100	100	100	100
Activity	Rehabilitated cell	Rehabilitated cell	Active cell	Closed landfill

CH_4 Max rate (m^3 year^{-1})	8.2×10^6	3.3×10^5	5.5×10^5	5.3×10^7
$\gamma = \frac{CH_4}{WasteTotal}$ **(m^3 year^{-1} Tons^{-1})**	4.1	0.8	0.8	2.5

Table 3: Summary of input parameters and results obtained by the LandGEM for different sites. CH_4 Max rate is the maximum annual CH_4 production rate found during the investigated period (in 2013 for La Gabarre landfill). γ is the ratio between CH_4 Max rate and the total amount of waste deposited in the landfill from its opening to its closure.

By performing a ranking of the landfills from the largest to the smallest amount of stored waste per year according to LandGEM, we have respectively: Kahrizak, La Gabarre and Akrotiri (B then A). The CH_4 Max rate has orders of magnitude from about 10^7 to 10^5 m^3 year^{-1} with a maximum value for Kahrizak (5.3×10^7 m^3 year-^{1}) and a minimum value for Akrotiri A (3.3×10^5 m^3 year^{-1}).

However, looking at the ratio γ, we observe a new ranking: La Gabarre (4.1 m^3 year^{-1} Tons-1), Kahrizak (2.5 m^3 year^{-1} Tons^{-1}) and Akrotiri (0.8 m^3 year^{-1} Tons^{-1}). This result is explained by k value because the L0 value is the same for all sites. La Gabarre's k value is the largest with 0.06 year^{-1}, while Akrotiri has the lowest value with 0.02 year^{-1}. Kahrizak and Akrotiri have a rainfall of less than 635 mm per year. k should be equal to 0.02 year^{-1} for both sites [31] but Kahrizak is a special case because LandGEM model consistently produced estimates for prediction of CH_4 emission lower (about 10%) than the real gas recovery rates [3]. Here, La Gabarre is the only site with a relative high rainfall of 635 mm per year.

In addition to rainfall, other factors such as temperature and moisture will favor the activity of methanogenic microorganisms. In Guadeloupe, the average annual temperature and humidity are respectively 26.4°C and 79% [22]. Even if these criteria are not taken into account in the calculation of LandGEM, they can enhance the production of methane at the landfill.

Conclusion

This is one of the few studies that make use of LandGEM output data in Caribbean area. The purpose of this study was to compare the results of this model with field measurements in a tropical insular environment. Most of the time, in Caribbean islands, there are open landfills that do not meet the standards. Collection and processing of biogas is uncommon. LandGEM provides an estimation of biogas potential production with a view to the installation of collection units to reduce methane emissions in the atmosphere.

By comparing LandGEM results with field measurements for biogas rate at La Gabarre, we obtain a ratio 1.94. This difference can be explained by several factors which are reviewed in this paper. More field experiments on the same landfill site in the future would allow us to empirically evaluate adequate L_0 value in Guadeloupe climate environment as well as the recovery efficiency of the collection system installed at La Gabarre landfill.

Once again, this study shows the importance of the k value for methane production modelling. According to the LandGEM results, we have established that the household waste at La Gabarre will generate 4 times as much methane as in arid areas like Akrotiri. The greenhouse effect related to the production of methane from the biodegradation of waste would be more important in Guadeloupe than in Greece. This shows the impact of climate conditions on the production of methane during methanogenesis step.

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Author Contributions

Thomas Plocoste, Sandra Jacoby-Koaly and Rose-Helen Petit have done the analysis and writing parts. André Roussas has been involved in the technical part.

Conflicts of Interest

The authors declare no conflict of interest.

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