Biomethane Generation Produced in Municipal Landfill

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Abstract

Biogas emerged as a renewable technology that converts waste organic matter into energy. Among its components, in terms of energy, methane is the most important chemical composition, particularly for the combustion process in vehicle engines. The use of methane derived from organic matter residues in landfills to replace fossil fuel minimizes the environmental impact, providing a significant reduction in the emission of greenhouse effect gases,as does the use of the amount of urban waste generated by the population in a planned way, with a specific technological focus at the forefront of generating solutions for ecological, social, economic and management challenges, which are themes that characterize smart cities. Thus, this study is based on the investigation and analysis of the potential of biogas generated by the theMunicipal Landfill West of Caucaia (MLWC - AterroSanitário Municipal Oeste de Caucaia/CE (ASMOC))with the objective of estimating the amount of methane gas produced in the referred landfill, based on data already published related to the amount of solid waste disposed at the landfill and applying it in the Biogas - Energy Generation and Use Aterro(version 1.0) software, developed by the Environmental Company of the State of São Paulo (ECSSP - Companhia Ambiental do Estado de São Paulo (CETESB)).As main outcomes, it was found that the landfill can generate, between the years 2018 to 2034, more than 3 million m^{3}of CH4, capable of supplying more than 201,362 vehicles fuel.

Keywords: Biogas, biomethan, renewable energy, smart cities.

1. INTRODUCTION

Since the industrial revolution, the demand for energy has grown every year around the world. According to Tolmasquin (2012), in Brazil, for the next decade, there will be an increase of 5.3% in energy per year, reaching a 372 million tons of oil equivalent.

The National Energy Balance (NEB – BalançoEnergético Nacional (BEN)) issued by the Ministry of Mines and Energy – MME (Ministério de Minas e Energia (MME)) 2019, reported that in 2018 the amount of carbon dioxide (CO2) emitted in Brazil reached 416.1 million tons of CO2 equivalent (Mt CO2 -eq), with the transportation sector accounting for 46.3% of this total, followed by the industrial sector, with 24.9%. Therefore, fossil fuels need to be replaced by clean, renewable energy sources in order to reduce emissions of greenhouse effect gases and carbon dioxide (NAHAWI et. Al, 2010). Faced with this scenario, biofuels gain prominence as a way to solve the world demand for energy and reduce the annual depletion rate of the world quantity of oil reserves, currently the main supplier of about 88% of the global energy (DADA and MBOHWA, 2017).

Another important point to emphasize is the growing presence of society in the urban area: according to a study by the United Nations (UN), more than half of the population on the planet (54.6% or 3.6 billion people) live in cities. This study indicates that, in 2050, 70% of the global population will live in cities (UN-Habitat, 2015). According to Rodríguez-Bolívar (2015), with the growth of cities, there is a concern by government officials to elaborate complex systems on key themes such as, for example, sustainable development, education, energy and environment, security and public services, among others. In view of this, an important theme to gain prominence from the government is related to the planning, management, and sustainability of urban waste. Thereby, as maintained by Vilaca et. al. (2014), projects aimed at creating infrastructure for the development of so-called *Smart Cities* are becoming a reality in several parts of the world, where a need for change in the energy sector is identified with a view to integrating renewable sources into the energy matrix.

With that, biofuel emerges as a clean and smart alternative to this aggravating factor in cities, as it is a product generated from common and available biomass sources, and its application circulates carbon between air and fuel, in addition to simultaneously solving problems related to the greenhouse effect and power shortages.

As stated by Qian et. al., (2017), most biofuels, such as biodiesel and ethanol, have physicochemical properties suitable for effective combustion in internal combustion engines, with or without minor modifications. In particular, most biofuels contain a certain proportion of molecular oxygen that can help fuel combustion.

In fact, the application of biofuels in internal combustion (IC) engines is already successful. For example, bioethanol has been widely used as a renewable substitute for gasoline in spark ignition (SI) engines (GALBE AND ZACCHI, 2002; HANSEN et al. 2005). Recently, a biogas preparation and application has been extensively studied (BOHUTSKYI and BOUWER, 2013; ESEN and YUKSEL 2013, ONWUDILI et al. 2013).

Jury et al. (2010) studied the life cycle of biogas production and compared it with that of natural gas, finding that, on human health and the ecosystem, biogas is not competitive enough with natural gas. However, biogas is competitive in relation to the effects of climate change, damage to resources and fossil energy demands. Divya et. al., (2015) summarized the preparation of anaerobic digesting biogas, noting that the inventions of specialized multistage digesters allow the monitoring, sampling and control of the main parameters, such as pH, temperature and speed of loading, which is a benefit for the conversion of biogas.

Nowadays, biogas is produced worldwide on a large scale. This production occurs from the anaerobic digestion of organic matter present in solid waste, sewage sludge, manure, among others. Its potential use as a source of clean energy has been emphasized in recent years (APPELS et al. 2008 and PETERSSON et al. 2009).The large volume of residues from agriculture and livestock exploration, sewage station and domestic treatment shows a high pollutant load that imposes the application of solutions that allow the reduction of damages caused to the environment, using as little energy as possible throughout the process (PECORA, 2006).

Based on this scenario, the present study proposed a survey on the amount of biogas generated in the Municipal Landfill West of Caucaia (MLWC - AterroSanitário Municipal Oeste de Caucaia/CE (ASMOC)) per year and on its potential use in the vehicle fleet as a substitute for fossil fuels, where, in reality of the current scenario, there is a need to change the energy sector in order to integrate renewable sources into the energy matrix. Thus, the use of solid waste to generate biogas refers to the development of so-called smart cities.

2. METHODS AND MATERIALS

The first phase of the work was to carry out a bibliographic and documentary review, specially in the libraries of the Federal University of Ceará (FUC – Universidade Federal do Ceará (UFC)), the State University of Ceará (SUC – UniversidadeEstadual do Ceará (UECE)) and the Federal Institute of Education, Science and Technology of Ceará (FIEC – Instituto Federal do Ceará (IFCE)), as well as collecting data and information from the State Environmental Superintendence (SES - SuperintendênciaEstadual do MeioAmbiente (SEMACE)), the Municipal Cleaning and Urbanization Company (MCUC -Empresa Municipal de Limpeza e Urbanização (EMLURB)) and the Secretariat of Infrastructure (SEINFRA - Secretaria da Infra-estrutura (SEINFRA)). In this sense, it is worth noting that:

- **SES (SEMACE) -** It is the main body responsible for the environmental licensing of potentially polluting enterprises in the State of Ceará and, therefore, it was responsible for licensing the Metropolitan Landfill West of Caucaia (MLWC), object of this study.
- **MCUC (EMLURB) –**It is responsible for part of the solid waste management system in Fortaleza;
- **SEINFRA (SEINFRA) -**It is responsible for the policy for monitoring the disposal of solid waste in the Metropolitan Region of Fortaleza.

As for the nature of the data, the main technical reports of these bodies were used and the period from 2018 to 2034 was used as reference, data compiled from the tables presented by SES (2017) on the basis of the Metropolitan Region of Fortaleza data - A (MRF – RegiãoMetropolitana de Fortaleza (RMF-A)).

The estimation of the biomethane potential of the Municipal Landfill of the West of Caucaia, from 2018 to 2034, was performed using the method developed by the Environmental Company of the State of São Paulo (ECSSP -Companhia Ambiental do Estado de São Paulo (CETESB)), within the scope of the agreement with the State Environment Secretariat São Paulo (SES/SP - Secretaria do MeioAmbiente do Estado de São Paulo (SMA/SP)) and the Ministry of Science and Technology (MST - Ministério da Ciência e Tecnologia (MCT)), the Biogas - Energy Generation and Use (Aterro - version 1.0) software.

2.1.Biogas - Energy Generation and Use (Aterro - version 1.0) software.

The Biogas - Energy Generation and Use (Aterro - version 1.0) software uses a mathematical model used by the United States Environmental Protection Agency (USEPA) to estimate methane generation at landfills in the United States. In the model, the methane generation estimate is made for each year of waste deposition at the landfill, according to equation 4, available in the Manual for the Biogas - Aterro 1.0 software (CETESB; SMA-SP; MCT, 2006).

$$Q_{CH_4} = K \times R_x \times L_0 \times e^{-k(x-t)} \quad (4)$$

Where:

Q_{CH4}– is the flow of methane generated in year x by urban solid waste (USW) deposited in year T [m3CH4 / year];

K - decay constant [1 / year];

R_x- waste flow in year x [kg_{USW}];

L_0- methane generation potential [m^3biogas/kg_{SWD}];

t -year of waste disposal at the landfill [year];

x - current year [year];

According to this model, the generation of Garbage Gas (GG) is the result of the anaerobic degradation of USW deposited at the landfill, reaching a maximum value in the year of its closure (period in which the reception of garbage ceases) and declining over the years subsequent. The efficiencyofbiogascollectionwasadoptedand 75%.

2.1.1. Constantes

As seen, in order to estimate methane generation, it is necessary to know some constants such as: decay constant and generation potential, which are described below according to the place of study.

- **Decay constant (K):**

The K value defines the time interval for the generation of methane from the deposition of waste. According to Mendes and Sobrinho (2007) the decay constant is a function of factors such as nutrient availability, pH, temperature and, mainly, humidity. The suggested values for K can vary from 0,01 $year^{-1}$ to 0,09 $year^{-1}$. Therefore, it is possible to choose a K value as a function of precipitation, according to Table 6.

Table 6- Suggested values for K.

Annual rainfall (mm)	***Values of k (1 / year)***		
	Relativelyinert	Moderatedecomposition	High decomposition
250	0,01	0,02	0,03
250-500	0,01	0,03	0,05
500-1000	0,02	0,05	0,06
1000	0,02	0,06	0,09

Source: World Bank(2004).

The Municipal Landfill of the West of Caucaia, which, according to data from the Climate-date, has an average annual rainfall that corresponds to about 1326 mm. Therefore, to perform the estimation calculations, the value of 0,09 $year^{-1}$.

- **Methane generation potential (L0):**

The variable L0 presents values that orbit between0,001 $m^3_{CH4biogas}/kg_{USW}$ for low organic waste, and 0,312 $m^3_{CH4biogas}/kg_{USW}$, for very organic waste (CETESB; SMA-SP; MCT, 2006).

The Biogas, generation and energy use - Aterro 1.0 software - suggests values for L_0 taking into account the representativeness of organic matter in relation to the history of waste disposal at the landfill. Thus, according to the gravimetric composition, the portion of organic matter corresponds to approximately 35% of the landfilled waste. Therefore, thechosenL_0valuewas0,12 $m^3_{CH4biogas}/kg_{USW}$.

2.2. Estimated fleet of fueled vehicles

The methodology used to calculate the number of cars fueled by the biomethane production of the chosen landfill was based on the ABNT NBR NM ISO 11439/2019 regulation - Gas cylinders - High pressure cylinders for the storage of natural gas as fuel on board of automotive vehicles.

This Regulation establishes the minimum requirements for light, refillable cylinders, for exclusive use in storage on board high-pressure natural gas, as fuel for motor vehicles, to which the cylinders must be attached. The service conditions of these cylinders do not cover the external loads that can occur in the event of collisions between vehicles, etc.

The 15 m³ cylinder (option most installed in automobiles) was chosen, which is equivalent to about 21 liters of gasoline or 28 liters of ethanol, thus dividing the biomethane generated in the landfill and the volume of the installed gas cylinder, according to Equation 5

$$.Fueledvehicles = \frac{Flowestimate}{standard\ 15\, m^3\ cylinder} \quad (5)$$

3. RESULTS AND DISCUSSIONS

In this chapter, initially the landfill design and characteristics and the history and future estimate of urban solid waste (USW) found in the literature at MLWC will be presented, in addition to the results obtained in the technical analysis of the use of biogas from the landfill using the Biogas - Energy Generation and Use (Aterro - version 1.0) software.

3.1. Study area characterization

The study area of the present work is the Municipal Sanitary Landfill west of Caucaia (MLWC), Figure 20, which is located on highway BR-020, city of Caucaia, state of Ceará - CE. Currently, the landfill serves the cities of Fortaleza and Caucaia and was designed for the final disposal of Class II solid waste. The landfill has an area of 123 hectares, of which 78 hectares are destined to receive USW. The way in which USW is disposed occurs by the trench or ditch method and by the area method (LINARD, 2010).

Figure 20 - Aerial photography of MLWC.

Source: Google Earth (2020).

According to Linard (2010), the MLWC was built by the Government of the State of Ceará in 1990, initially conceived to receive the USW in the city of Caucaia / CE. However, in 1998, through a legal instrument called the Term of Assignment of Use of the Government of the State of Ceará, the MLWC also became the place of deposition of the USW of Fortaleza on condition that it bears all the administrative and operational costs from that, exempting Caucaia from any burden.

In accordance with the Environmental Impact Report presented to the State Superintendence of the Environment (SES), MLWC underwent the expansion process and the area was dimensioned to meet the demand for the next 16 years and 8 months, thus functioning until 2034 (VIANA, 2018).

3.2. Characterization of the USW arranged in the MLWC

As stated on the report of the analysis of the gravimetric composition of the waste from the Municipal Landfill of the West of Caucaia, released by SES in the regional plan for the integrated management of solid waste (SEMACE, 2017), it was found that the predominant components in the composition are paper or cardboard, plastic, organic matter and waste. However, organic matter is the one with the highest percentage for the two municipalities that MLWC benefits (Caucaia and Fortaleza), of approximately 32% and 35%, respectively, seen in Table 7.

Table 7 - Estimated Typology of MLWC Urban Solid Waste (%).

County / Material	Caucaia	Fortaleza
Ferrous Metal	0	1,5
Non-ferrous metal	3,42	0,5
Hard plastic	9,39	3,1
Soft plastic	1,04	10,9
Paper / cardboard	14,77	8,0

Glass	9,82	1,5
Organicmatter	32,0	35,0
Sanitaryorigin	6,91	6,2
Tetrapack	1,05	1,2
Cloths / rags	7,38	4
Rejects	7,75	18,5

Source:SEMACE (SES), Panorama tabelas RMF-A, 2017.

The gravimetric composition reflects the percentage of each component in relation to the total weight of the sample analyzed. The knowledge of this characteristic allows the use of recyclable fractions for commercialization and of organic matter to producegarbage compounds. In addition, this variable is basic information for various activities, such as monitoring landfills, implementing selective collection and analyzing the viability of composting and recycling plants (SANTOS, 2016).

Santos (2016) also states that the detailed knowledge about the USW is advantageous not only for the personnel responsible for the landfill, but for the planning of the management system as a whole. Based on Monteiro et. al (2001), this knowledge can assist in estimating the quantities to be collected in each region of the city, in the design of collection vehicles and transfer stations, in the implementation of selective collection, recycling and composting programs, in the manufacture of odor inhibitors etc.

3.3. History and future estimate of waste grounding at MLWC

The Municipal Landfill of Oeste de Caucaia has been in operation since 1990. Table 8 describes the total values of waste received by the landfill until 2009.

Table 8 - History of waste grounding at MLWC.

Year	Total solid waste (ton / year)
1992	40.000
1993	40.000
1994	40.000
1995	40.000
1996	40.000
1997	40.000
1998	1.065.169
1999	1.012.934
2000	1.113.743
2001	1.055.160
2002	1.004.630
2003	864.737

2004	730.067
2005	944.083
2006	1.062.288
2007	1.188.843
2008	1.186.655
2009	1.436.782

Source: ACFOR, EMLURB (MCUC), ECOFOR (2010).

The notable increase in the quantity of USW disposed in the landfill observed since 1998 is due to the fact that, until 1997, MLWC received only the garbage from the municipality of Caucaia and, in subsequent years, also received the city's waste from Fortaleza.

According to Panorama Tables RMF-A released by SEMACE (SES), (2017) in the regional plan for integrated solid waste management, an average USW estimate from 2018 to 2034 was released for the municipalities of Caucaia and Fortaleza (Table 9). This estimate was made based on per capita generation information from the National Sanitation Information System (NSIS - Sistema Nacional de InformaçõessobreSaneamento (SNIS), 2016), presenting an average flow of USW in the period from 2018 to 2034 in the total of 1,608,225 ton / year, an important value for the calculation of methane production.

Table 9 - Estimated Average USW (2018 to 2037).

Year	Total solid waste (ton / year)
2018	1.423.494,00
2019	1.444.777,20
2020	1.466.398,80
2021	1.488.366,00
2022	1.510.689,60
2023	1.533.369,60
2024	1.556.409,60
2025	1.579.820,40
2026	1.603.612,80
2027	1.627.786,80
2028	1.652.353,20
2029	1.677.315,60
2030	1.702.681,20
2031	1.728.460,80
2032	1.754.658,00
2033	1.781.287,20
2034	1.808.344,80

Source: SEMACE (SES), Panorama tabelas RMF-A(2017).

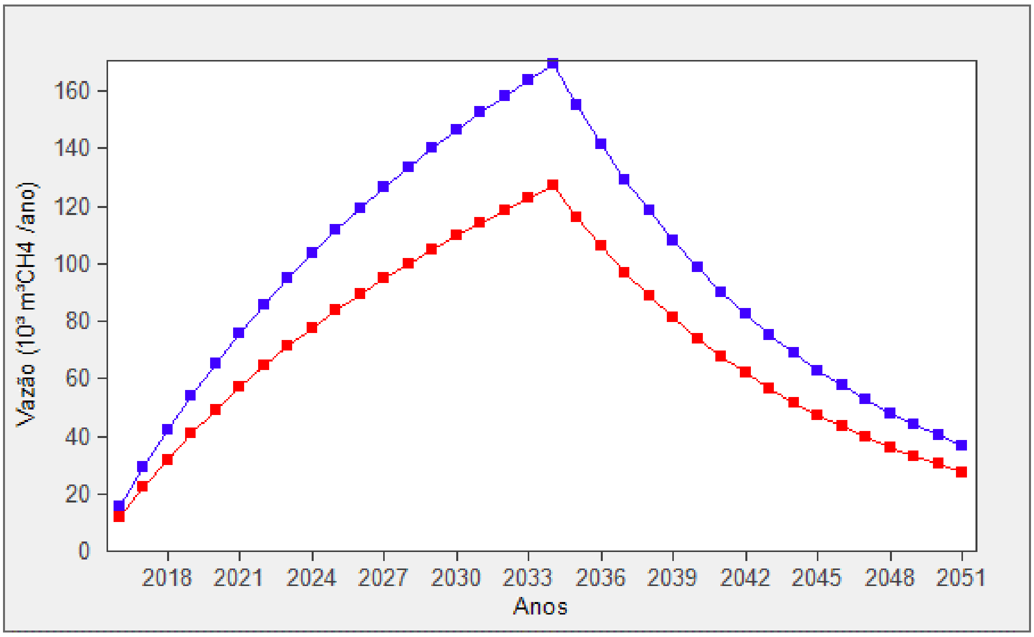
3.4. Present and future potential of MWLC

To calculate the methane production, the model of the Environmental Company of the State of São Paulo (ECSSP) was used, as reported in the previous chapter, and the volumes of landfilled waste were used, since the year in which the Renewable Natural Gas -Fortaleza project (RNG Fortaleza - Gás Natural Renovável Fortaleza (GNR Fortaleza)) was implemented until the end of the landfill operating license, which covers the period between the years 2018 and 2034; the methane generation potential (L_0) equal to 0,12 $m^3_{CH4biogás}/kg_{RSU}$suggested by the software due to the percentage of organic matter present in the landfilled waste; and the decay constant (K) equal to 0,09 ano^{-1}, taking into account the annual precipitation of the municipality of Caucaia / CE, in which the landfill is installed.

Other important values for the elaboration of the methane flow estimate is the identification of the Baseline that corresponds to the scenario that collect data related to the Greenhouse Effect Gas (GEG) emissions that occurred prior to the implementation of the project. According to Linard (2010), in the MLWC, as there is no GG controlled combustion procedure (this is partially burned), it would be characterized as partial emission of gas into the atmosphere, being a fraction burned with certain periodicity in drains, in the calculations used 20% of the flaring baseline, as well as a 95% biogas flaring efficiency (values suggested by the software).

Figure 21 shows the estimate of methane production from 2018 to 2050. This time interval was used, since, after 2050, methane production is already inexpressive and is not feasible for making energy use.

Figure 21 - Graph of the CH4 flow estimate in the MLWC.



Source: the Author.

The blue curve in the graph represents the amount of methane resulting from the decomposition of the MSW disposed there and the corresponding one in red, the amount that is actually collected (the 75% lock).

It can be seen in Figure 21 that in the first years of the installation of RNG - Fortaleza, there is an increase in the level of methane generation, because the unit has received, every year, a greater amount of USW, thus making the process more efficient and faster. of anaerobic digestion and, consequently, it appears that there is a greater production of methane gas.

Bearing in mind that methane production is directly proportional to the quantities of landfilled waste, 2034 has the maximum peak production of CH4. In that year, it is expected that the landfill will receive the largest amount of solid waste, totaling around 1,808,344.80 tons / year, as estimated by SEMACE (SES), (2017) in Panorama RMF-A tables.

From the year of 2035, the flow values will decrease because there is no grounding of new quantities of waste at the unit, as the landfill is only licensed to operate until 2034. However, it is worth noting that the landfill's operating license may be extended depending on legal procedural steps.

According to Azevedo (2000), the calorific value of biogas ranges from 17 - 34 MJ / kg (higher) to 15-34 MJ / kg (lower). The calorific value of some gases, including methane, is shown in Table 10. When compared to other fuels, the feasibility of using methane as a fuel in automobiles is possible, allowing the minimization of environmental impacts and ensuring a significant reduction in the emission of greenhouse effect gases.

However, for the application of biogas in internal combustion engines, it is necessary that it be purified, in order to reach the specifications of natural gas, and, finally, be used in vehicles adapted for this fuel (NADALETTI et. al, 2015).

Table 10 - Values of lower calorific value (LCV) and superior (SCV) of different gases.

Gas	LCV andSCV (MJ/kg)
Methane	**55,5 – 50,0**
Natural gas	50,0 – 45,0
Gasoline	47,3 – 44,0
Light diesel	44,8 – 42,5
Heavy Diesel	43,8 – 41,4
Refinedgas	42,3 – 38,6
Ethanol	29,7 – 26,9
Charcoal	29,7 – n/d
Methanol	22,7 – 20,0

Source: Azevedo, 2000.

Table 11 shows the estimated values of methane production, in m³ / year, which can be generated between the years 2018 and 2050 by the MLWC and the number of vehicles that can be refueled in that period. Given this, it can be argued that the Municipal Landfill of the West of Caucaía will produce, in 2034, approximately 163,050 m³ of methane.

Thus, considering the 15 m³ cylinder (option most installed in automobiles), which is equivalent to about 21 liters of gasoline or 28 liters of ethanol, it is estimated that, in that year, the amount of biogas generated is enough to supply more than 10,000 cars. Furthermore, when using biogas instead of fossil fuels, there will be a reduction in the emission of gases harmful to my environment, the risk of contamination of soil, air and water resources, in addition to social impacts, such as improving people's quality of life. around the system and decreased breathing problems, among others.

Table 11 - Estimated CH_4 production in the MLWC and number of vehicles fueled between 2018 and 2050..

Year	Flowestimate (10^3 m^3 / year)	Fueled vehicles (10^3 / year)
2018	15,37	1,02
2019	29,65	1,98
2020	42,94	2,86
2021	55,32	3,69
2022	66,87	4,46
2023	77,68	5,18
2024	87,8	5,85
2025	97,31	6,49
2026	106,25	7,08
2027	114,68	7,65
2028	122,66	8,18
2029	130,22	8,68
2030	137,4	9,16
2031	144,24	9,62
2032	150,78	10,05
2033	157,04	10,47
2034	163,05	10,84
2035	149,02	9,93
2036	136,19	9,08
2037	124,47	8,30
2038	113,76	7,58
2039	103,97	6,93
2040	95,02	6,33
2041	86,84	5,79
2042	79,37	5,29
2043	72,53	4,84
2044	66,29	4,42

2045	60,59	4,04
2046	55,37	3,69
2047	50,61	3,37
2048	46,25	3,08
2049	42,27	2,82
2050	38,63	2,58
Total	**3020,440**	**201,662**

Source: theAuthor.

According to this study, the MWLC in the period from 2018 to 2050 could generate about 3,020,440 m³ of biogas, which can supply fuel to the fleet estimated at 201,362 vehicles. Thus, it can be concluded that the large volume of waste generated in the cities of Fortaleza and Caucaia / CE, which would normally be a problem, became the solution for supplying the vehicle fleet.

As a result, the biogas plant is a sustainable output for waste generated in cities. When implementing a biogas plant, an environmental liability is removed, and it can be transformed into something useful. Thus, the MWLC biogas generation plant can serve as a showcase for smart city technologies for government officials to be inspired and understand solutions for improving the management of urban solid waste. The smart city is an efficient, technologically advanced, green, and socially inclusive city (Vanolo, 2014). That is, smart city applications put a specific technological focus at the forefront of generating solutions for ecological, social, economic and management challenges (YIGITCANLAR, 2016).

In turn, this can be seen as a process of change in which the exploitation of resources, investment targeting, technological development and institutional change are consistent with present and future needs (IMPERATIVES 1987). Denoting the relationship between economics, aspects of social and environmental sustainability based on a combination of indicators for each of these components (AHVENNIEMI et al. 2017).

Yigitcanlar and Lee (2014) propose that the city be ecologically healthy, using advanced technologies and having economically productive and environmentally efficient industries, in addition to a responsible and harmonious systematic culture and a physically aesthetic and functional landscape.

4. CONCLUSIONS

From the results presented, it can be concluded that:

The gravimetric composition of the waste from the Municipal Landfill of the West of Caucaia (MLWC) found that the predominant components are paper or cardboard, plastic, organic matter and waste. However, organic matter is present in greater quantity.

According to the estimate, in the period from 2018 to 2034 the average flow of USW will be more than 1 million tons per year dumped in the MWLC, a value that corresponds to the garbage collected in the cities of Fortaleza and Caiucaia - CE, and even more than the cities were within the concept of smart cities, they would still generate solid waste.

The feasibility in using landfill gases to replace fuels derived from oil allows the minimization of environmental impacts and ensures a significant reduction in the emission of greenhouse effect gases.

It expects the maximum production of CH4 in 2034. In that year, the landfill will receive the largest amount of solid waste, reaching a maximum value in the year of its closure (period in which the receipt of waste ceases) and declining over the following years.

In 2034, biomethane production at the landfill is approximately 163,050 m³ of methane. It is estimated that, in that year, enough to supply more than 10,000 cars.

The Municipal Landfill West of Caucaia generates about 3,020,440 m³ of biogas, which could supply fuel to the fleet estimated at 201,362 vehicles. In a socioeconomic perspective, the landfill allows the use of biogas for the automobile sector, reducing fuel costs, and decreasing the spread of diseases in the human respiratory system.

The MLWC biogas generation plant can serve as a showcase for smart city technologies for government officials to be inspired and understand solutions for improving the management of urban solid waste.

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