Mapping Biogas from Municipal Waste as Potential Clean Energy Areas in Central Mexico, Using Geographic Information Systems

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Abstract. Waste-to-energy (WtE) plants are management facilities that burn waste to produce electricity. Biogas plants are one form of WtE options. A prospective model to estimate biogas from solid waste was developed, combining two methodologies: Tchobanoglous and collaborators and the EPA-1996s equation. The first one uses urban solid waste composition to estimate biogas, while the later one converts biogas flow data into energy units (Mega-watts, MW). The resulting model is capable of estimating biogas from waste composition within any municipality in the study area (Mexico City, State of Mexico, Morelos, Puebla, and Querétaro) and it is also able to translate the potential biogas flow (in thousands of m^3/day) into megawatts (MW). A GIS was used to create choropleth maps representing the biogas volume that can be potentially produced in each region. The results obtained show that the Iztapalapa delegation in Mexico City could generate 62.63 MW. The Chimalhuacán region could reach 46 MW as well as some areas in Morelos. The use of solid waste in the Sierra Norte de Puebla was estimated in an energy capacity of 49.41 MW and finally, the Bajío Queretano obtained 37.83 MW. The GIS-location model was conceived for its use in prospective studies to locate potential WtE projects. The calculated energy from urban solid waste is presented in the form of graphs and maps, thus reflecting which region has a better potentiality for using this type of clean energy. This information is an important foundation for further spatial analyses using GIS and decision making.

Keywords: GIS · Biogas · Municipalities

1 Introduction

Waste generation within a place depends on multiple variables such as location, socioeconomic level, attitudes, and culture. In Mexico, between 1950 and 2017, the per capita generation went from 300 to 994 g per inhabitant per day. The State of Mexico along with Mexico City have the largest waste generation in the country, reflecting 16% and 12%

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respectively of the national total, which for 2017 has been estimated at 120,128 t/day [1].

From the total municipal waste generated in Mexico, half of it corresponds to organic compounds (46.42%) [1] whose decomposition can be used to generate compost (via aerobic decomposition) or biomethane (via anaerobic decomposition) either in sanitary landfills or in facilities created for this purpose (WtE facilities). Waste-to-energy (WtE) plants are management facilities that burn waste to produce electricity. Biogas plants are one form of WtE options [2, 3].

Biogas is made up of approximately 50% methane (CH_4) and 50% carbon dioxide (CO_2), both of which are known as greenhouse gases (GHG), with methane being 24.5 times more contributing to the greenhouse effect than carbon dioxide [4]. Methane has a high energy content and is capable of being captured and used as a renewable energy source [2, 3]. Furthermore, methane represents a risk due to its high calorific value and its flammability, therefore it is not recommended that it be produced and emitted to the atmosphere under uncontrolled conditions [5].

In Mexico, the most used method for waste disposal is the sanitary landfill (as the best option) and open dumps (as the worst) [1]. A decomposition process of organic waste also occurs within sanitary landfills due to the environmental conditions created by the temperature, the presence or not of oxygen, the waste characteristics, and the age of the sanitary landfill. All this leads to a series of products, where liquid waste, better known as leachate, and gases such as biogas stand out [5].

Nowadays, several countries in the world, use biogas to generate energy, Europe is the world leader in biogas electricity production, with more than 10 GW installed and a number of 17,400 biogas plants [6]. As for Mexico, it uses only 2.4% of the biogas generated in landfills, since we lack the necessary infrastructure for its collection, or because there is not enough capacity for its economically viable exploitation [7, 8].

Many biogas projects from municipal waste to generate energy, have not been adequately developed in the country, due to multiple factors such as lack of planning, lack of financing, or lack of government support. Geographic Information Systems (GIS) can be used to generate prospective information. In this case, as for the potential biogas from waste that can be produced in a place and obtain technical data for feasibility projects. This would also allow us to comply with the obligations that Mexico has signed (regarding greenhouse gas emissions).

In the first part of this project, a prospective biogas model was developed from the composition of municipal waste to identify those areas that could have a high potential for its use as a clean energy option. In the second part, the results obtained from the model were combined with geo-referenced information on the location of municipalities, and a GIS that shows the results obtained through choropleth maps. In the third (and future) part of this project, the aim is to use the powerful tools of GIS to make spatial analyzes that allow finding the optimal location of future waste treatment facilities for their conversion into energy, looking for generating inter-municipal associations to make them environmentally friendly; technically viable and economically feasible.

This article focuses on the second phase of the project: the combination of the model results, with geospatial data, and the construction of maps.

2 State of the Art

As an introduction and to give an idea of how the results of the model were obtained, a brief explanation of the two models used for making up the prospective biogas model is presented.

2.1 Biogas Models in Sanitary Landfills

Numerous mathematical models allow for the estimation of potential biogas from waste. They also serve to assess potential risks associated with explosions and fires. Biogas models can also be used to evaluate project feasibility [4, 9–14].

Each model has its parameters, however, the amount of degradable waste deposited in sanitary landfills is considered a constant parameter among all of them. The most widely used models in Mexico are presented below.

The Tchobanoglous et al. Model

The Tchobanoglous and collaborators method involves the anaerobic digestion process that takes place in the organic fraction of waste, where its predominant products are carbon dioxide and methane, the main components of biogas. The organic fraction is divided into two classifications: 1) those residues that decompose rapidly (three months to five years) identified as RDS and 2) the residues that decompose slowly (up to 50 years or more) identified as SDS. This model requires knowing the elemental chemical composition of the waste (carbon [C], hydrogen [H], oxygen [O], and nitrogen [N]) [5]. The volume of gases emitted during the anaerobic decomposition can be represented by Eq. 1:

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3 \quad (1)$$

This model uses waste generation and waste composition data of each sub-product, the moisture content and dry weight to obtain the percentages of carbon, hydrogen, oxygen, nitrogen, sulfur, and ash from the waste. Having this composition and using the molecular weights of each chemical element, the waste chemical formula is obtained [identified as CHON]. Subsequently, from the chemical formula, the volumes of methane and carbon dioxide are estimated with the help of the specific weights of each compound. This methodology estimates the theoretical total amount of biogas that could be produced from the organic fraction of waste.

The LandGEM Model

Before the LandGEM model, the US Environmental Protection Agency (USEPA) published in the "Landfill Gas-to-Energy Project Development Manual" [15], an equation that correlates the potential for electrical energy to the biogas volume obtained from municipal waste decomposition. At the same time this equation sets the energy content of the biogas as a constant of approximately 500 Btu/ft3, and the heat rate for combustion engines in 12,000 Btu/kW, concluding in Eq. 2:

$$\text{kW} = \text{biogas flow}\left(\frac{ft^3}{day}\right) * \text{energy content}\left(\frac{Btu}{ft^3}\right) * \frac{1}{heat\ rate}\left(\frac{Btu}{kW}\right) * \frac{1\,day}{24\,hours} \quad (2)$$

Where:
kW = Gross power generation potential
Biogas flow = ft^3 of biogas obtained using the Tchobanoglous et al., method.
Energy content = the energy content of biogas (approximately 500 Btu/ft^3)
Heat rate of biogas for internal combustion engines = 12,000 Btu/kW

Later in 2001, the LandGEM model was created [16], which determines the volume of methane generated, using the potential for methane generation and the mass of deposited residues, mathematically described as shown in Eq. 3:

$$Q_{CH4} = \sum_{I=1}^{n} k(Lo)(Mi)\left(e^{-kt}\right) \tag{3}$$

Where:
QCH_4 = Methane emission rate [m^3CH_4/t]
k = methane generation constant [t − 1]
Lo = methane generation potential [m^3CH_4/kg waste]
Mi = mass of residues in the i-th section [mg]
t = time elapsed since the waste deposit (annual) [t]

At least 1 MW of electricity is expected to be generated within a sanitary landfill, to consider it useable for energy production [17, 18].

The Mexican Biogas Model
The Landfill Methane Outreach Program (LMOP) together with the United States Environmental Protection Agency (EPA) and other government agencies, developed the first Mexican Biogas model, to help operators and owners of landfills evaluate the importance and viability of capturing biogas and use it energetically [13]. This new version of the model uses a first-degree degradation equation. The following information is required for the estimation of biogas:

- Year of opening.
- Year of closure.
- Annual provisions.
- The annual average rainfall.
- Efficiency of the biogas collection system.

The last two biogas estimation models are more complicated to apply to landfills in Mexico since, currently, most of the parameters are difficult to obtain and there is no assurance of their veracity. Besides, these are applied to landfills that have a minimum operating period of one year.

There are other mathematical models, but this paper is not intended to explain the intricated details of the biogas-model created for this project but to present the biogas and potential energy maps obtained. However, it is important to highlight that, currently, no model uses waste data prospectively (as a decision-making tool where no landfills or WtE facilities exist). The one developed in the first part of this project does do that. It is also the first one that takes official information from State Waste Programs as input data.

2.2 Mapping Biogas Data

Montaño and collaborators established potential sites for biogas production in Mexico (Fig. 1). They determined that the minimum value for a place in the central zone of Mexico is 3 MW [19]. As a result of this research, and for the purpose of this study, it was established that the biogas generated by municipal waste is energetically usable from 3 MW on. This value is equivalent to 50,000 m^3 biogas per day.

Fig. 1. Potential sites for biogas production in Mexico. Source: self elaboration from Montaño et al. (2009).

3 Methods

The biogas estimation model selected for this project was the one of Tchobanoglous and collaborators, since, as previously mentioned, it allows obtaining the volume of biogas generated by the organic fraction (rapid and slowly degradable), starting-off solely on the composition and amount of waste. This type of information is vital to analyze real biogas rates, from the first three months to five years to 50 years or more.

Subsequently, to obtain the results in energy terms, the EPA-1996 equation was used, which requires the volumetric flow of biogas to provide results in terms of mega-watts (MW).

3.1 Making up the Biogas Model (1st Phase of the Project)

The central area of the Mexican Republic was chosen, specifically the states of Mexico City, the State of Mexico, Morelos, Puebla, and Querétaro because of the following reasons:

1. Waste generation: Mexico City and the State of Mexico are the two states that generate the most municipal waste in the entire country.
2. Neighboring states: Mexico City has borders with the State of Mexico and Morelos. Hidalgo, Puebla, and Querétaro are also part of the central states which have a significant contribution to the national waste generation.
3. Potential energy capacity: according to the study made by Montaño and collaborators, Querétaro and Puebla stood out for their electrical energy capacity coming from landfill gases (Montaño).
4. Data availability: the five states considered in the study have in common the availability of waste composition data for the entire state (or most of their municipalities), which made it possible to generalize data to the model.

Once the selected models and the study area were analyzed, it was determined to generate two information forms, 1) a general information form (Table 1), and 2) a specific information form (on waste from any selected municipality) (Table 2). These forms were the basis for completing the data required by the biogas estimation model. That is, the data from the five states of the study area were unified using the arrangement shown in Table 1 and Table 2.

Table 1. Structure of the general information form

General information					
Municipality	ID (CVE_Mun)	State	State ID	Region	Population

Table 2. Specific waste information form (for any municipality within the study area)

RDS[1] Waste sub-product (composition) (tonnes/day)	SDS[2] waste sub-product (composition) (tonnes/day)
Organic (food) waste	Plastics
Paper	Glass (labels on glass)
Cardboard	Metals
Garden waste	Textiles
	Wood
	Disposable diapers

[1] RDS stands for “rapid degradability subproduct” (in waste)
[2] SDS stands for “slow degradability subproduct” (in waste)

– *Waste information*: All the information regarding waste composition was obtained from the latest official reports available for each state. Then, the information was categorized using the forms shown in Table 1 and Table 2. The data were processed using Microsoft Excel.

– *Biogas estimation*: The chemical formula of waste for any municipality is obtained using the Eq. 1. Then, the biogas is obtained using the method described by Tchobanoglous and collaborators [5].
– *Conversion to megawatts:* The biogas flow is converted to potential electricity using Eq. 2 and the method described by the EPA model [15].

3.2 Building the Biogas GIS (2st Phase of the Project)

The information from a total of 405 municipalities was processed and calculated by the Excel biogas model and the results were arranged in five categories:

– Waste generation (in tonnes/day)
– Biogas from RDS fraction (in thousand m^3/day)
– Biogas from the SDS fraction (in thousand m^3/day)
– Potential biogas generation (sum of RDS and SDS fractions) (in thousand m^3/day)
– Potential electricity generation from biogas (in megawatts MW)

Later, the information of the biogas-model was exported as independent csv files for each state.

Geodatabase: Vectorial layers (shapefiles) were obtained for the same municipalities. They were downloaded from the National Geostatistical Framework webpage. Shapefiles for each state (Mexico City, State of Mexico, Morelos, Queretaro, and Puebla) and its municipalities were obtained and depurated to preserve only the ID field (CVE_MUN), the state ID (CVE_ENT) and the municipality name field (NOM_MUN).

On the other hand, the cvs files exported from Excel were joined to their respective shapefiles (using the municipality ID as the common ID). This was done using the table union option in the software QGIS Pi.

Choropleth Maps Definition: After the shapefiles were joined to the CSV tables, new shapefiles were created for each state. A GIS project was made using the QGIS Pi software. Maps showing the biogas flow and the potential MW production were created by mapping the corresponding field on the attributes table of each state (V4 and V5). Graphs were also created showing the results for each municipality.

4 Results

The results obtained from the biogas model were classified in a database for each Mexican state using the following codes (Table 3):

Each municipality has a unique code assigned by the National Institute of Statistics, Geography and Informatics (INEGI). Therefore, the database was constructed using the geo-code of each municipality as its exclusive ID (CVE_MUN) and then each field on the table corresponds to a result from the biogas model (as previously indicated in Table 3). At the same time, each state is divided into different regions (according to their official state programs) to facilitate environmental management, including waste

Table 3. Codes to identify the results from the biogas model.

Waste generation (tonnes/day)	V1
Biogas from RDS fraction (thousand m3/day)	V2
Biogas from SDS fraction (thousand m3/day)	V3
Potential biogas generation (thousand m3/day)	V4
Potential electricity generation from biogas (MW)	V5

management issues. These regions were considered for arranging the information in the database since it is important to consider neighborhood properties for future spatial analysis. For example, two or more municipalities with low biogas potential can unite in the same project and make energy from biogas feasible for all of them if they find the best location for a WtE facility).

4.1 Geodatabase Structure

The following figures show the results of every municipality for three of the states within the study area in the following order: Mexico City (Table 4), Morelos (Table 5)

Table 4. Mexico City's waste generation, biogas and potential electricity results.

CVE_MUN	V1	V2	V3	V4	V5
010	665.00	154.56	290.11	444.67	28.59
002	507.00	146.08	140.29	286.36	18.41
014	699.00	172.48	189.92	362.40	23.30
003	795.00	185.02	228.75	413.77	26.61
004	183.00				
015	1293.00	433.72	335.09	768.81	49.43
005	1704.00	464.24	477.83	942.07	60.58
006	472.00				0.00
007	2272.00	594.27	379.74	974.01	62.63
008	257.00				
016	812.00	198.32	219.51	417.83	26.87
009	118.00	29.71	36.03	65.74	4.23
011	351.00				
012	853.00	178.82	312.82	491.64	31.61
017	842.00	213.29	264.05	477.34	30.69
013	435.00	110.45	134.35	244.79	15.74

Table 5. Morelos' waste generation, biogas and potential electricity results.

CV_MUN	V1	V2	V3	V4	V5
007	553.03	126.63	237.82	364.45	23.43
008	79.922	18.30	34.37	52.67	3.39
011	279.26	63.95	120.09	184.03	11.83
018	114.07	26.12	49.05	75.17	4.83
028	59.96	13.73	25.78	39.51	2.54
002	8.974	1.75	5.46	7.21	0.46
016	7.876	1.54	4.79	6.33	0.41
022	9.159	1.79	5.57	7.36	0.47
030	26.797	5.23	16.30	21.53	1.38
005	5.67	1.03	3.83	4.87	0.31
014	7.27	2.12	1.77	3.89	0.25
015	14.79	2.69	10.00	12.69	0.82
021	4.76	0.86	3.22	4.08	0.26
004	64.9	11.57	43.26	54.82	3.53
020	47	8.38	31.33	39.70	2.55
029	124.5	22.19	82.98	105.17	6.76
003	21.95	5.24	8.92	14.16	0.91
010	8.75	2.09	3.55	5.64	0.36
013	7.23	1.73	2.94	4.66	0.30
033	6.57	1.57	2.67	4.24	0.27
019	17.47	4.17	7.10	11.27	0.72
032	4	0.95	1.62	2.58	0.17
023	3.56	0.71	1.92	2.63	0.17
026	12.41	2.47	6.68	9.15	0.59
027	8.2	1.63	4.41	6.05	0.39
001	9.43	2.02	3.82	5.84	0.38
012	36.91	7.89	14.97	22.86	1.47
017	44.73	9.57	18.14	27.70	1.78
024	15.51	3.32	6.29	9.61	0.62
025	22.85	4.89	9.26	14.15	0.91
031	25.33	5.42	10.27	15.69	1.01
006	226.67	52.57	75.94	128.52	8.26
009	12.26	2.24	7.79	10.04	0.65

and Queretaro (Table 6). The municipalities geo-codes in all tables are not shown in numerical order but alphabetical order instead, according to the region they belong to.

The results for the State of Mexico and Puebla are not shown here because these two states have more than 150 municipalities each and that makes their tables very large.

Table 6. Querétaro's waste generation, biogas and potential electricity results.

CV_MUN	V1	V2	V3	V4	V5
014	789.72	193.14	316.43	509.57	32.77
006	123.01	30.07	48.64	78.71	5.06
001	30.02	7.34	11.86	19.20	1.23
008	12.98	3.17	5.13	8.30	0.53
011	119.94	29.33	47.37	76.70	4.93
012	42.97	10.51	16.98	27.49	1.77
016	188.94	46.21	74.63	120.85	7.77
017	47.98	11.74	18.95	30.69	1.97
007	40.99	10.02	16.20	26.22	1.69
004	40	9.78	15.79	25.57	1.64
005	44.98	11.00	17.76	28.76	1.85
013	17.01	4.15	6.73	10.88	0.70
018	15.99	3.92	6.32	10.23	0.66
002	10.476	2.69	4.32	7.01	0.45
003	10.02	2.45	3.95	6.40	0.41
009	15.99	3.92	6.32	10.23	0.66
015	5.52	1.22	1.97	3.19	0.20
010	14.99	3.67	5.91	9.59	0.62

4.2 Biogas Choropleth Maps

The GIS-location model was conceived for its use in prospective studies to locate potential WtE projects. The calculated biogas flow from urban solid waste is presented in the form of graphs and choropleth maps for all the states included in the study area (Figs. 2, 3, 4, 5, and 6):

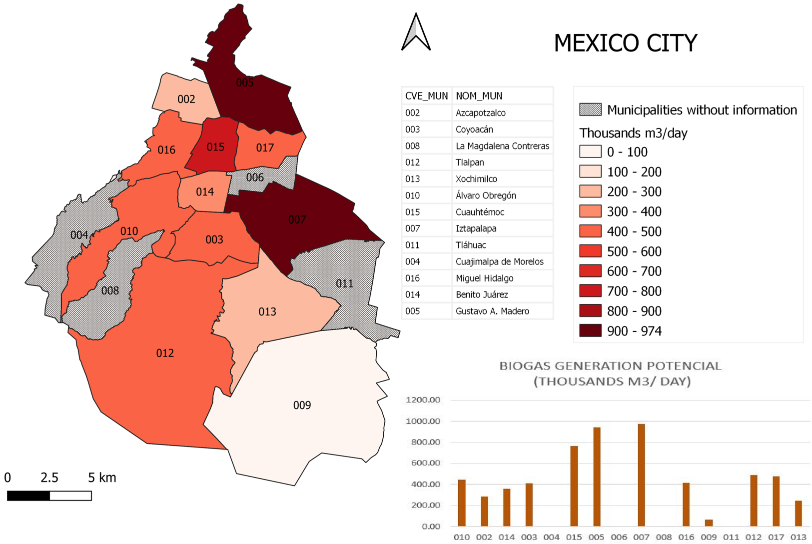

Fig. 2. Potential biogas flow within Mexico City municipalities.

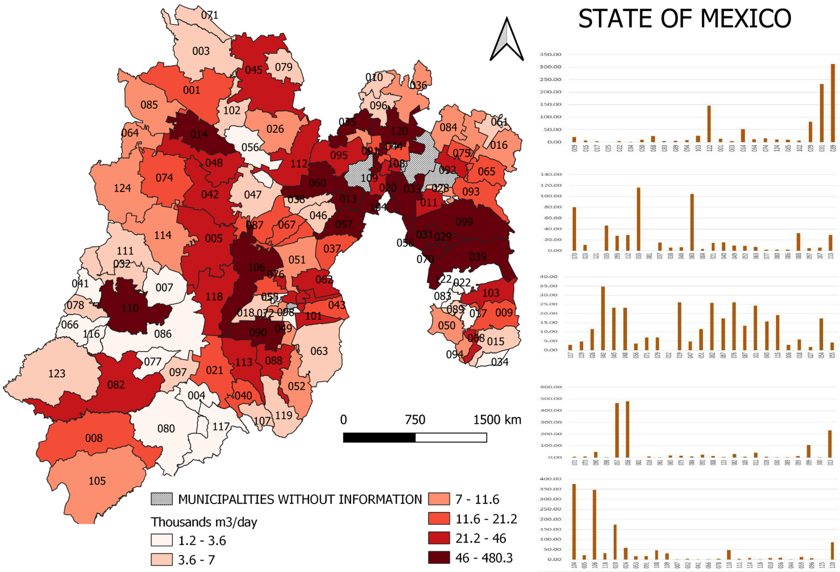

Fig. 3. Potential biogas flow within the State of Mexico municipalities.

The largest generation of biogas comes from the municipalities of Iztapalapa (CVE_MUN 007) with 974 thousand m^3/day and Gustavo A. Madero (CVE_MUN 005) with 942 thousand m^3/day. This generation is directly related to the population since Iztapalapa is the most populous, followed by Gustavo A. Madero, a pattern that is constant for any state. Together they represent 32.54% of the biogas emission in the whole Mexico City. However, it is important to mention that, in demographic terms, they are in fourth place with 117 km^2, and in sixth place with 94 km^2, respectively.

This means that high populated areas represent a serious problem for waste management and the location of any waste management facility.

For the State of Mexico, the municipalities with the highest biogas flows are Nezahualcóyotl (CVE_MUN 058) with 480 thousand m^3/day, followed by Naucalpan de Juárez (CVE_MUN 057) with 463 thousand m^3/day.

In turn, the municipalities of Valle de Chalco Solidaridad, Atlacomulco, Chicoloapan Chimalhuacán, Ixtapaluca, La Paz, Ecatepec, Nicolás Romero, Texcoco, Atizapán de Zaragoza, Tlalnepantla de Baz, Toluca, Coacalco de Berriozábal, Cuautitlán and Zumpango within, generate bio range from 100 to 300 thousand m^3/day. On the other hand, despite the fact that municipalities below the value of 50 thousand m^3 of biogas per day dominate, the inter-municipality concept would offer a solution for the efficient use of waste (instead of landfilling).

It is important to note that Mexico City and the State of Mexico together account for 28% of waste generation in the country [1]. This means that the potential for a feasible WtE project within this area is high. As a matter of fact, Mexico City had already made a licitation for a WtE project in 2017–2018. Unfortunately, it was cancelled due to political reasons. Mexico City, being the capital of the country, does not have any landfill within its territory and its waste is sent to the State of Mexico and Morelos [20].

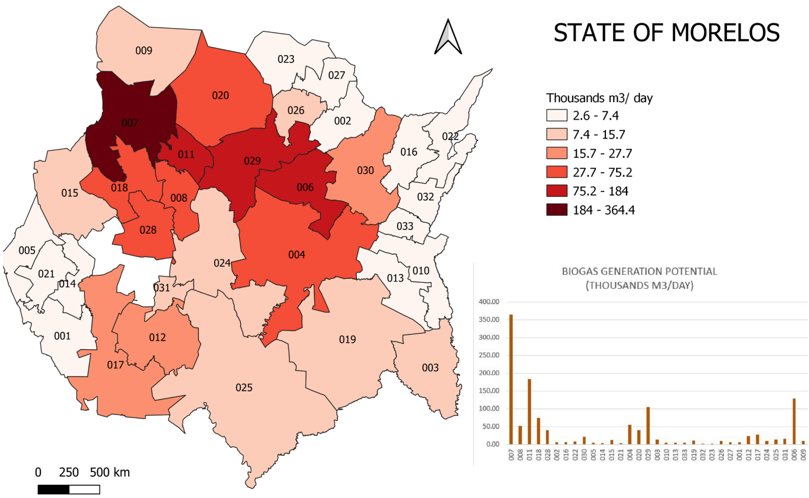

Fig. 4. Potential biogas flow within Morelos' municipalities.

In Morelos the municipalities with the highest biogas flows are Jiutepec (CVE_MUN 011) with 184 thousand m^3/day, Yautepec (CVE_MUN 029) with 105 thousand m^3/day, and Temixco (CVE_MUN 018) with 75 thousand m^3/day.

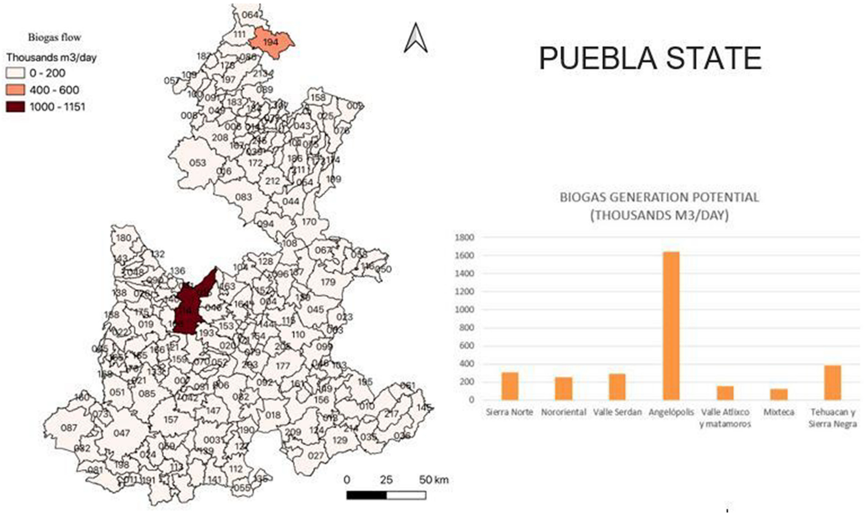

Fig. 5. Potential biogas flow within Puebla municipalities.

Puebla represents the largest territory with 33,919 km^2 and 217 municipalities. It is important to note that, as shown in the cartographic representation, most of the municipalities barely exceed 12 thousand m^3 per day of biogas, which is considered a non-feasible value for WtE projects. However, this state is a clear example of the possibility that "low-biogas municipalities" might come together, to sum up, and locale a WtE facility where neighbors towns can benefit from the same project. This, of course, would require more detailed technical studies. The municipalities with the highest biogas-flows are:

- Amozoc (CVE_MUN 015) with 69 thousand m^3/day,
- Tehuacán (CVE_MUN 156) with 182 thousand m^3/day and
- The city of Puebla (capital) (CVE_MUN 114) with 1 million 151 thousand m^3/day.

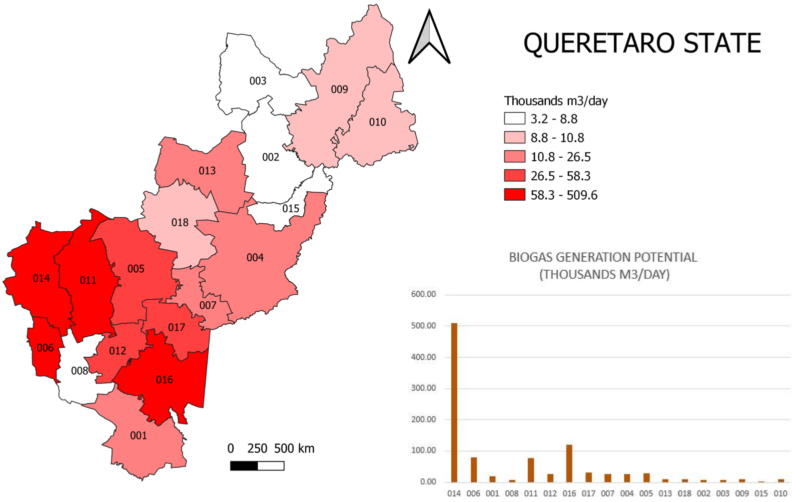

Fig. 6. Potential biogas flow within Querétaro municipalities.

The state of Querétaro has the lowest values of biogas compared to other states in the study area. Most of its municipalities are in the range of 3,000 m^3 per day up to 30,000 m^3 of biogas per day.

The municipalities with the highest biogas flows are Querétaro (CVE_MUN 014) with 509 thousand m^3/day, San Juan del Río (CVE_MUN 016) with 120 thousand m^3/day; Corregidora (CVE_MUN 006), with 78 thousand m^3/day and El Marqués (CVE_MUN 011) with 76 thousand and m^3/day. The choropleth map reflects that the largest generation of biogas occurs in the southern part of the state. This information is key for the possible construction of an interstate facility in association with the State of Mexico.

4.3 Potential Electricity Generation from Biogas

The following figures (Fig. 7, 8, 9 and 10) show the results in potential megawatts obtained from biogas. Each municipality is now labeled with the field V5 (MW) instead of the municipality ID (CVE_MUN). Each municipality has a unique calculated value in MW. Even when a municipality might have less than 3 MW potential, this does not mean that it is out of a WtE project. What we want to explore with future spatial analyses are pre-feasibility scenarios where two or more neighbor municipalities can join together to explore inter-municipal WtE projects. Spatial analyses can also be useful to find the best location for a WtE project considering other geographic aspects such as topography, travel time, costs, etc.

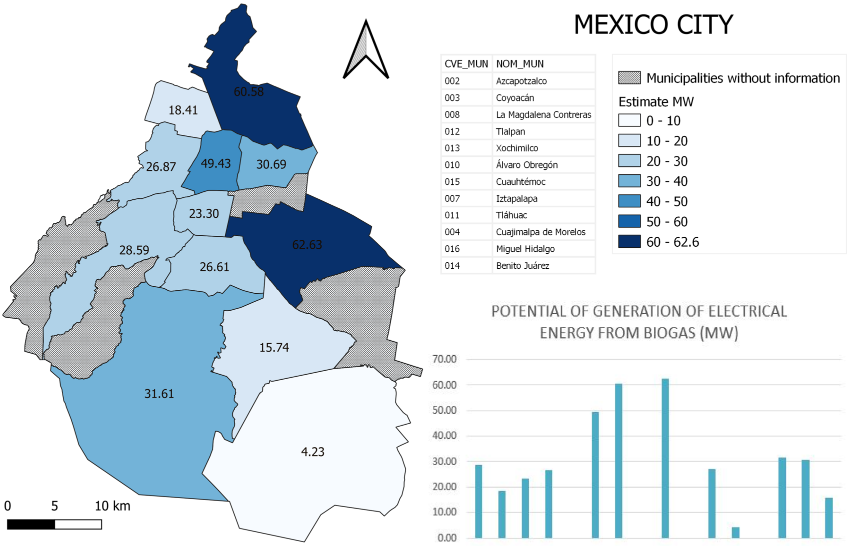

Fig. 7. Potential MW production from biogas in Mexico City.

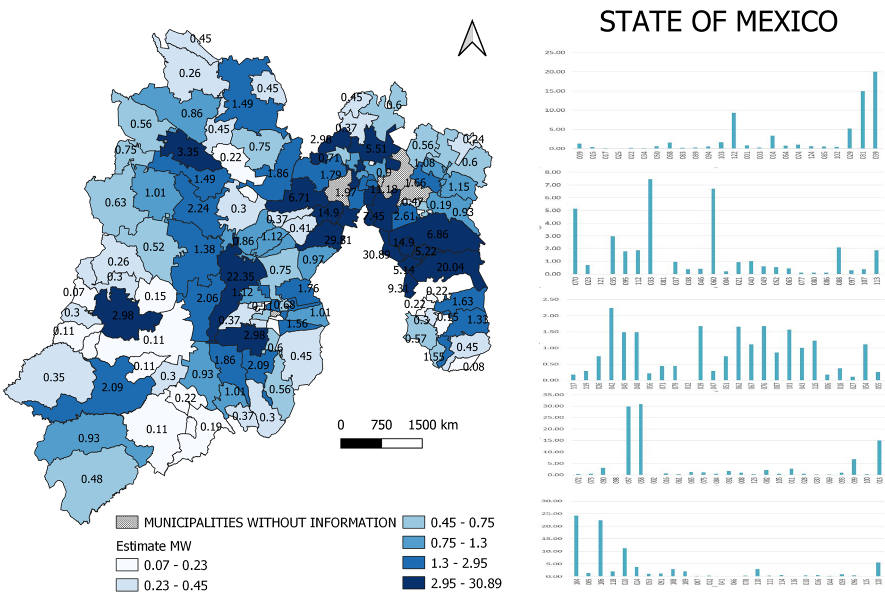

Fig. 8. Potential MW generation from biogas in the State of Mexico.

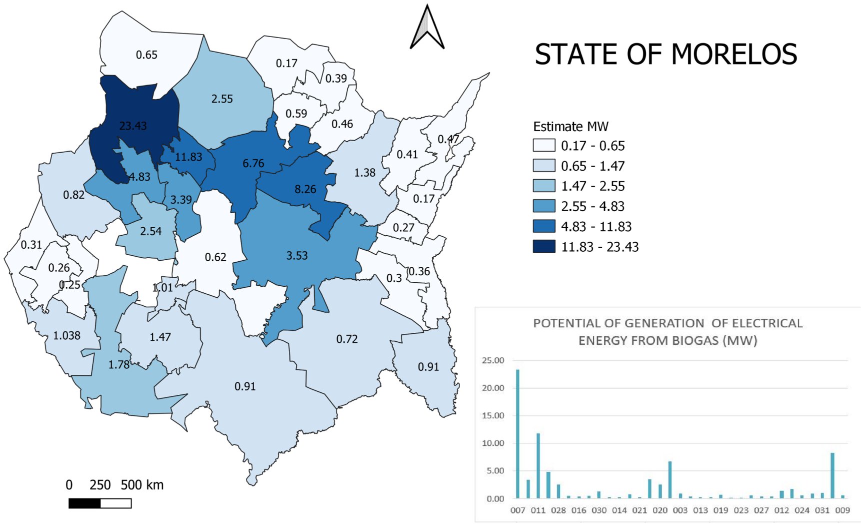

Fig. 9. Potential MW production from biogas in Morelos.

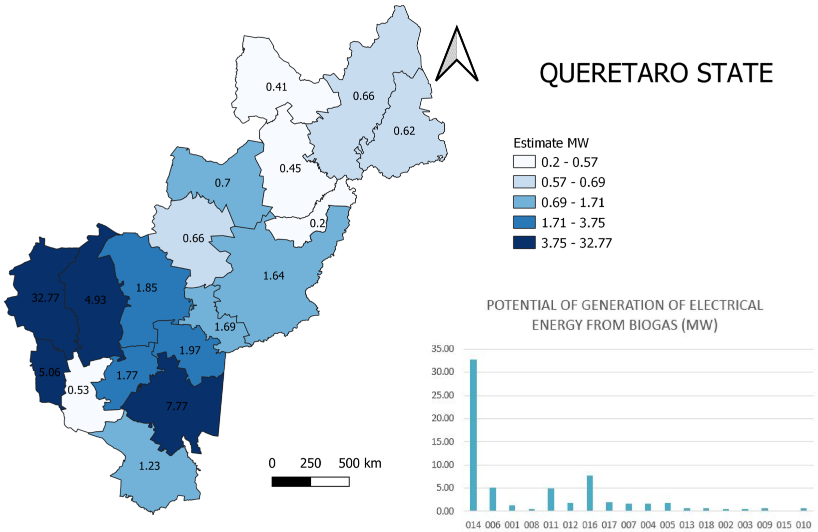

Fig. 10. Potential MW production from biogas in Querétaro.

4.4 Future Research

The next part of this project consists of having the data onto a web GIS platform and create additional layers of information to perform future spatial analyses and to make the information available for public use. The shapefiles were uploaded onto the ArcGIS online platform to show an example on how the results would look like (Fig. 11):

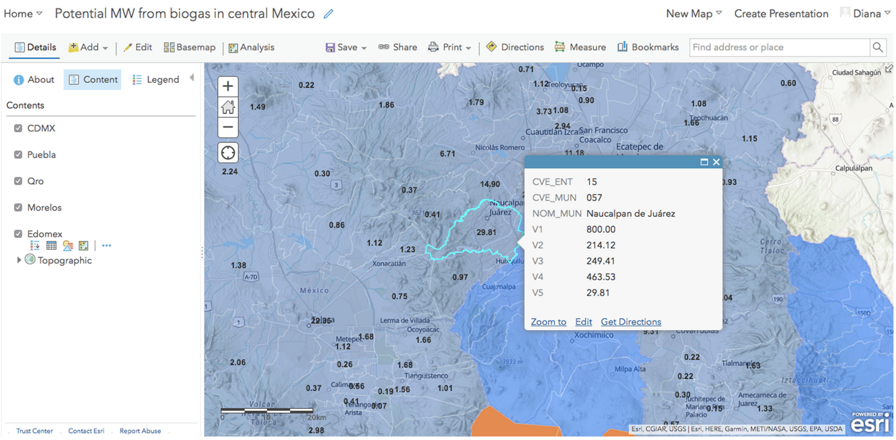

Fig. 11. An example of how can layers showing potential megawatts from biogas be shown on a web GIS platform.

5 Conclusions

A prospective biogas calculation model was developed from municipal waste. The model, identified as the "Biogas-estimation model for central states of Mexico", combines the methodology of Tchobanoglous and collaborators and the EPA 1996 equation. The resulting model is capable of estimating biogas from waste composition within any municipality in the study area (Mexico City, State of Mexico, Morelos, Puebla, and Querétaro) and it is also able to translate the potential biogas flow (in thousands of m^3/day) into megawatts (MW). This model can be applied in any other state (even from another country) as long as waste data composition and generation are available.

The biogas results calculated by the model were later migrated to a GIS project and several maps were created showing the potential biogas production as well as potential electricity within each municipality in the study area. A GIS was used to create choropleth maps representing the biogas volume that can be potentially produced in each region.

The results obtained show that the Iztapalapa delegation in Mexico City could generate 62.63 MW. The Chimalhuacán region could reach 46 MW as well as some areas in Morelos. The use of solid waste in the Sierra Norte de Puebla was estimated in an energy capacity of 49.41 MW and finally, the Bajío queretano obtained 37.83 MW.

The next phase of this study will include having the biogas and potential energy results available onto a GIS web platform for performing spatial analyses to find potential best locations for inter-municipal WtE projects.

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