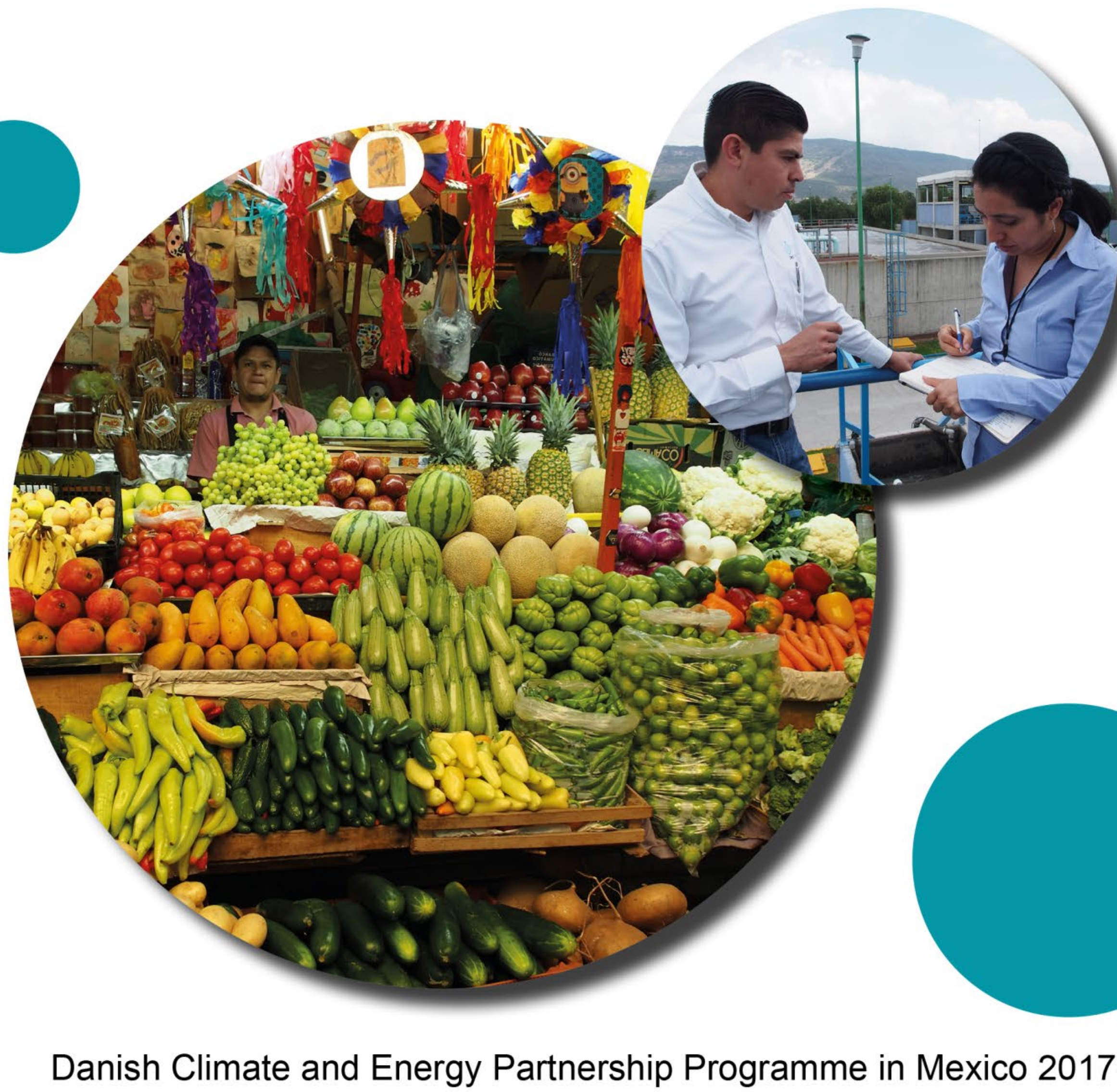
Danish Energy Agency

Pre-feasibility studies for biogas

in Guanajuato 2018-2019



Danish Climate and Energy Partnership Programme in Mexico 2017-2020
Bioenergy

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1. INTRODUCTION

1.1. Scope and objective of the prefeasibility study

The Energy Partnership Program between Mexico and Denmark seeks to provide input for a Mexican biomass roadmap that includes the implementation of an action plan and feasibility studies, as well as the proposal of additional incentives to promote a sustainable use of biomass in the energy mix.

Based on available information the present pre-feasibility study in Guanajuato was chosen by SENER and Danish Energy Agency as a promising biogas production project in Mexico.

The aim of the "Pre-feasibility study for biogas in Guanajuato" is to evaluate if a biogas project at the selected site is feasible. The lessons learned in this study, and in similar pre-feasibility studies done in Sonora, can be useful for other potential projects in Mexico. More than 2 000 anaerobic digesters (AD) currently exist in Mexico. These AD-plants are typically farm-based, lagoon covered biogas plants, varying in size from small household plants of less than 25 m^3 to larger plants with a reactor capacity of more than 1000 m^3. The agricultural plants treat slurry and manure from livestock. Additionally, 9 anaerobic digestion systems treat the sludge at municipal wastewater treatments plants (WWTP) and normally produce electricity for the self-consumption of the plant. Furthermore, there are anaerobic digesters in operation at industries such as breweries, dairy and cheese factories, soft drinks facilities, yeast factories, pulp and paper and paper factories, tequila industry and snacks and candies factories. There are also a few AD reactors in slaughterhouses and meat treatment facilities.

According to recent assessments, AD plants in Mexico are typically not very efficient in terms of energy production, and do not contribute with the SEN (Sistema Eléctrico Nacional). The vast majority of the agricultural plants were established for environmental reasons and many of them just burn the biogas.

Ultimately, the pre-feasibility studies were intended to identify and analyse technical and regulatory challenges in order to propose specific measures to alleviate the identified problematic barriers. The latter should provide input for future decisions of SENER or at the State level, regarding the role played by biogas in the energy mix in Mexico, which is promising but quite limited in the current situation.

This study aims to evaluate if the Metropolitan Waste Water Treatment Plant (WWTP) "San Jerónimo", could receive wastes generated in slaughterhouses, as well as the biodegradable wastes from municipal markets and consider these as additional feedstocks to the WWTP sludge, which is currently used to produce biogas.

1.1. Guanajuato framework

The economic activities in the State of Guanajuato are mainly from the tertiary sector (57.6%) and later from the secondary (38.7%) and the primary sector (3.7%) (Instituto Nacional de Estadística y Geografía, 2016).

The Ecology Institute of Guanajuato State (Unidad de Transparencia y Archivos del Poder Ejecutivo del Estado de Guanajuato, 2017) has reported the generation of 3 680 tonnes/day of waste, only with 2012-based data. According to that report, there are two complying landfills (1 public and 1 private) with appropriate regulations (NOM-083-SEMARNAT-2003). There are 20 partially complying landfills and 29 non-complying sanitary landfills. There is a lack of information about waste generation in Guanajuato State.

The State of Guanajuato has 71 regulated slaughterhouses (SADER y SENASICA, 2019), eight central markets (CONACCA, 2018; INEGI, 2017) and 106 public markets in the municipalities of the state (INEGI, 2017).

According to CEA Guanajuato, the State had a wastewater treatment coverage of 74% in 2012.

Guanajuato has been included in the group of the more affected Mexican states due to hazardous sites (SEMARNAT, 2010). In 2017 the State of Guanajuato had 48 contaminated or potentially contaminated sites (SEMARNAT, 2019).

2. SITE VISITS

The consultants visited the following sites in Guanajuato during the field trips that took place on June 14th -15th and August 19th – 20th, both in 2018:

A. San Jerónimo WWTP
B. Slaughterhouses
   a. Municipal slaughterhouse of Purísima del Rincón
   b. Municipal slaughterhouse of San Francisco del Rincón
C. Markets
   a. Municipal market of La Purísima del Rincón “Ing. Manuel G. Aranda”
   b. Municipal market of San Francisco del Rincón
D. Dairy industry “Lácteos Jalpa”
E. Agricultural lands
F. Municipal landfill

Figure B.1 shows the map with the places considered for the pre-feasibility study in Guanajuato, where the polygons of the Purísima del Rincón and San Francisco del Rincón municipalities are shown. In addition, Figure 2 shows the locations (with closer proximity) of the places involved in the project.

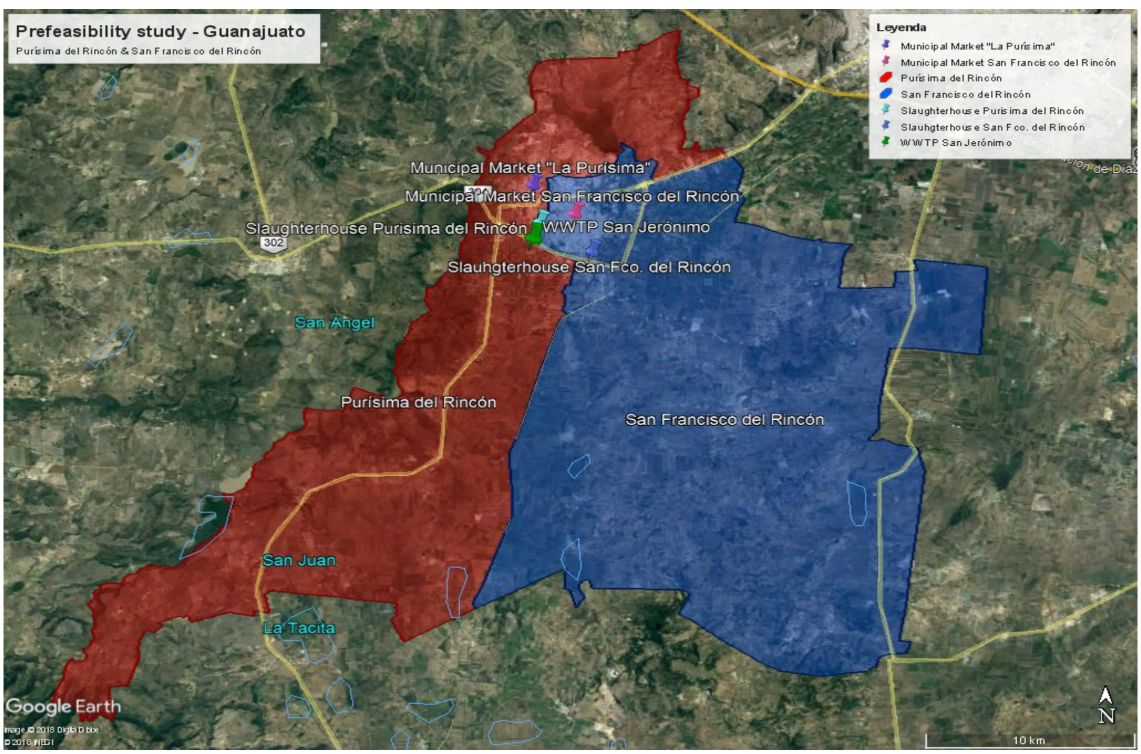

Figure 1. Location of the places related with the pre-feasibility study in Guanajuato.

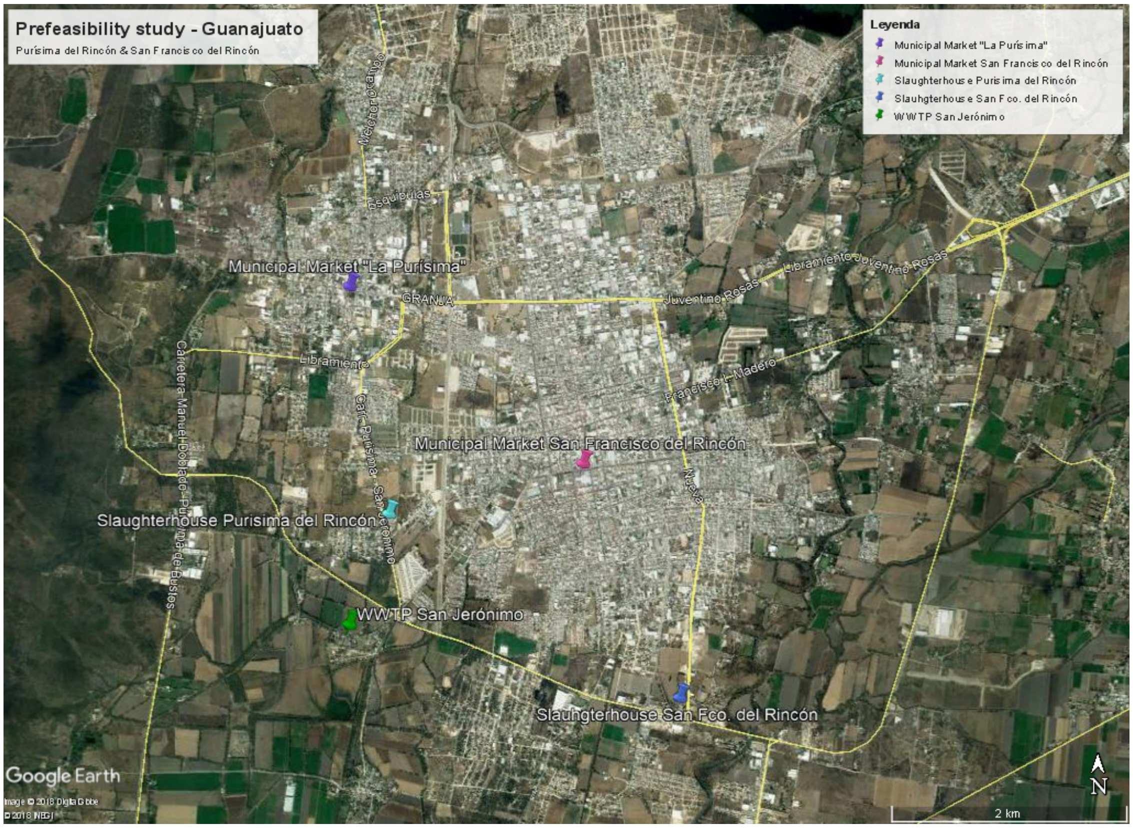

Figure 2. **Location of the places related with the pre-feasibility study in Guanajuato (major proximity)**

2.1. San Jerónimo WWTP

The "San Jerónimo" Municipal Wastewater Treatment Plant is serving the municipalities of "El Rincón" in the west side of Guanajuato, adjacent to Jalisco. It is operated by the "Intermunicipal System for Wastewater Treatment and Disposal Services for the Municipalities of "El Rincón" (SITRATA -for its acronym in Spanish-).

With an area of more than 17 thousand square meters, the "San Jerónimo" WWTP has a design flow of 250 L/s, although currently only 140 L/s are treated. The quality of the affluent is, COD: 734 mg/L, BOD: 355 mg/L, SST: 284 mg/L; while the effluent complies with regulation NOM-003-SEMARNAT-1997. The next Figure (3) shows the satellite view of the WWTP. In general, Figure 4 shows the scheme of the treatment train of the WWTP.

The total electrical demand of the plant is 836 kW, while the operational demand is 513. 62 kW.

Figure 3. **Satellite view of the WWTP "San Jerónimo"**

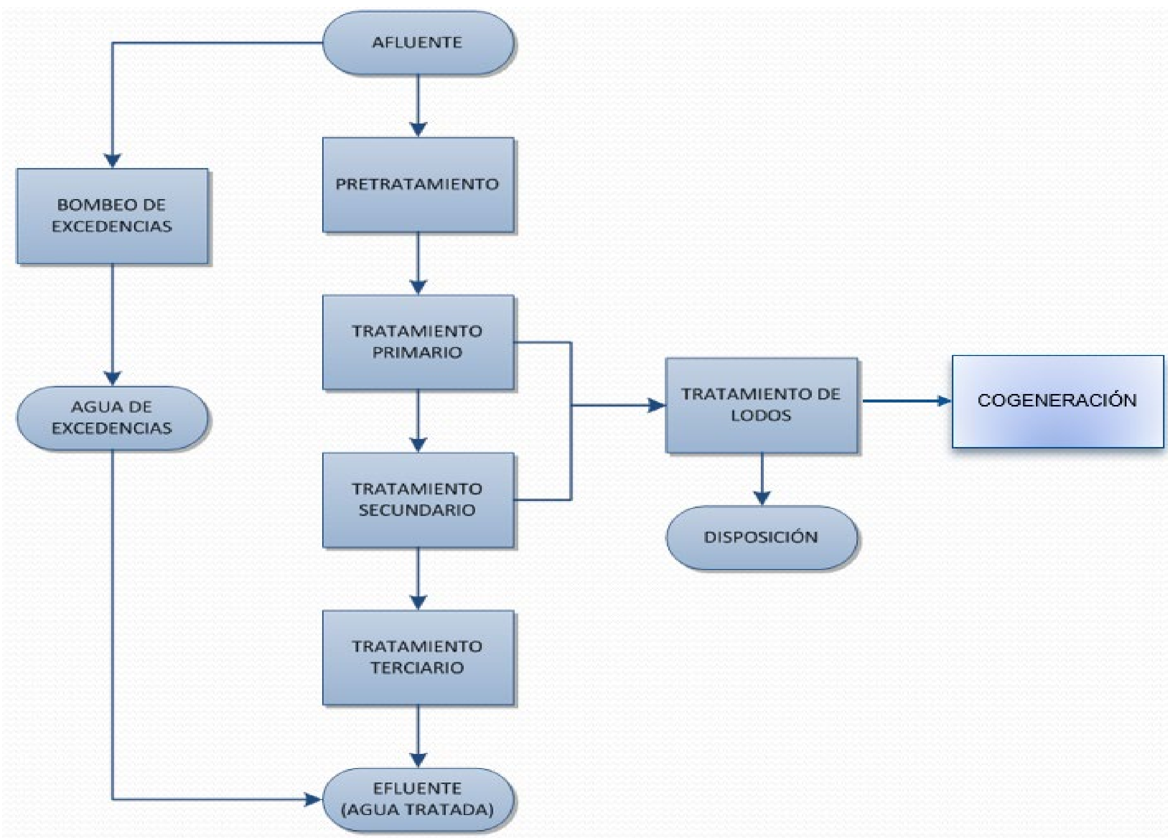

Figure 4. **Treatment train of the wastewater**

The treatment train starts with pretreatment consisting of medium (19 mm) and fine (5 mm) screens (Figure 5). In addition, it has the structure of a vortex degritter (Figure B.6), which is not working, so the sand removal is being done manually 3 or 4 times per year (stopping the operation of the plant completely). A more effective way of separating grit is under study. At the entrance of the process the surpluses are being pumped until the end of the process and these end up in the treated water

Figure 5. **Pretreatment**

Figure 6. **Structure of the vortex degritter**

Next, the water continues the process with the primary treatment (Figure 7): primary clarifier with a design residence time of 2.5 h (currently, 3 h). In the process, a 30 % removal of the BOD, as well as 50-60 % of the TSS is presented. It is proposed to use coagulant to increase to 70 % -approximately- the removal of TSS.

Figure 7. Panoramic view of primary sedimentation

The process continues with the aerobic reactor composed of an anoxic zone and the aerobic zone itself, which has 6 hours of hydraulic retention time (HRT). During the visit, it was commented that it was necessary to corroborate the operation of the anoxic zone since, although the removal of nitrogen is adequate, less amount of flow than that stipulated in the design is being treated. The blower (150 hp) consumes 30 to 40% of the total energy of the WWTP (Figure 8).

Finally, within the water treatment, there is the disinfection, for which trichlor is used as a disinfectant (Figure 9).

Figure 8. Aerobic reactor

Figure 9. Disinfection

For the handling and treatment of the sludge generated in the primary and secondary treatment levels (Figure 10, primary and secondary sludge pumping station), there is an anaerobic digester (Figure 11). The concentration of total solids (TS) in the sludge to be digested is 4%. The digester volume is 2 414 m^3 with a volume of sludge fed from 70 to 90 m^3 and a residence time design of 17.5 days. The feeding frequency is every two hours and the mixing frequency every 3 hours, while a purge is made in 4 hours. Also, from 30 to 40 m^3 of biogas are produced each hour. Finally, the digester operates at a temperature of 35-37°C and with a pH of 6.5 to 7.5.

The methane concentration of the biogas generated is 53-55%. For the biogas storage, there is a gas holder, shown in Figure B.12; as well as the biogas burning system (Figure 13).

Figure 10. **Primary and secondary sludge pumping station**

Figure 11. Anaerobic digester

Figure 12. **Gas holder**

Figure 13. **Biogas burning system**

Besides, for handling sludge there is a thickener table which works for 6 to 8 h which concentrates the sludge from 1-2 to 4 % of solids (Figure 14).

Figure 14. **Thickener and sludge pumping station just up-stream anaerobic digester**

Additionally, there is a cogeneration system based on the biogas generated (Figure 15). It can cogenerate up to 330 kW during 3-4 hours per day; however, only 136 kW are being cogenerated because just 102m^3 of biogas is introduced into the CHP per hour of operation (10-12% of the total energy requirement of the plant is cogenerated). The cost and schedule of the tariffs are as follows:

Table 1. **Electric rates in WWTP San Jerónimo**

Bajío

Tarifa	Descripción	Int. Horario	Cargo	Unidades	JUN-18
GDMTH	Gran demanda en media tensión horaria	-	Fijo	$/mes	436.21
		Base	Variable (Energía)	$/kWh	0.8331
		Intermedia	Variable (Energía)	$/kWh	1.4641
		Punta	Variable (Energía)	$/kWh	1.6653
		-	Distribución	$/kW	90.16
		-	Capacidad	$/kW	302.01

Los cargos de las tarifas finales del suministro básico descritos en este apartado, corresponden a la integración de los cargos por Transmisión, Distribución, Operación del CENACE, Operación del Suministrador Básico, Servicios Conexos No MEM, Energía y Capacidad.

Table 2. Schedule of the different electric rates in WWTP San Jerónimo

Regiones Central, Noreste, Noroeste, Norte, Peninsular y Sur

Del primer domingo de abril al sábado anterior al último domingo de octubre

Día de la semana	Base	Intermedio	Punta
lunes a viernes	0:00 - 6:00	6:00 - 20:00 22:00 - 24:00	20:00 - 22:00
sábado	0:00 - 7:00	7:00 - 24:00	
domingo y festivo	0:00 - 19:00	19:00 - 24:00	

Del último domingo de octubre al sábado anterior al primer domingo de abril

Día de la semana	Base	Intermedio	Punta
lunes a viernes	0:00 - 6:00	6:00 - 18:00 22:00 - 24:00	18:00 - 22:00
sábado	0:00 - 8:00	8:00 - 19:00 21:00 - 24:00	19:00 - 21:00
domingo y festivo	0:00 - 18:00	18:00 - 24:00	

Furthermore, it was mentioned that the cost to raise the energy to the network is very high (approximately 5 million pesos), this is the cost for permits and investment in equipment. So, the energy generated is only used for self-consumption.

Figure 15. Cogeneration system

The WWTP has a well functioning anaerobic digester (CSTR) which has over capacity due to the low inlet flow compared to design values:

- WWTP inlet flow =140lps (designed for 250lps)
- Sludge residence time in digester= 26 days (designed for 17.5d)

It also has a co-generation system, which is only used few hours a day, not at full capacity and efficiency, and the thermal energy produced is not used (just the electricity):

- Operation= 3-4hrs per day (average)
- Low working load= 65% (recommended 90%)
- Electrical efficiency= 25% (maximum 39%)
- Low energy produced= 1.3 kWh/m^3 biogas (it could reach 1.86kWh/m^3)
- Just 40% of biogas is used, the rest is used for digester heating and 10-20% is burned
- Thermal energy from jacket water is not used.

It is therefore relevant to evaluate if organic waste from nearby industries can be used as additional feedstocks for the biogas production.

2.2. Slaughterhouses

2.2.1. Municipal slaughterhouse of Purísima del Rincón

The Purísima del Rincón municipal slaughterhouse is located 1.5 km far from San Jerónimo WWTP, on the Purísima-San Jerónimo S/N road, Purísima de Bustos, Purísima del Rincón, Guanajuato. Its coordinates are: 21°0'40.06'' N, 101°52'28.76'' W. Figure B.16 presents the satellite view of the slaughterhouse.

Figure 16. Satellite view of the slaughter of "Purísima del Rincón"

This slaughterhouse sacrifices 35 cows and 80 pigs per day, where each cow produces 10 liters of blood, while for each pig, 4 liters of blood are obtained. According to the above, 350 liters of cow blood per day are generated and 320 L/d of pig blood. Approximately, 80% of the blood has a use. Cow blood is used for swine feeding, while swine blood is used to produce “moronga”. The waste is given away and collected in the facilities of the slaughterhouse.

Furthermore, the installations are washed three times per day, using a total of 30 m^3/d of water, 20 % of the blood generated is mixed with the water used for washing. The water is sent to the pit with fat. Figure 17 shows washing with traces of blood.

Figure 17. Slaughterhouse washing

In addition to the blood, there are other residues such as fat, which is sent to a pit (serpentine type) where it is dried, it also contains traces of blood. Figure 18 shows the pit with the fat.

Furthermore, about 2 to 3 tons per day of ruminal content are obtained, which is mixed in the truck with the fat and the remains of blood that have been dried. These wastes are taken to cultivation plots as fertilizer or soil improver. The transport is carried out by the trucks of the slaughterhouse, where bad odors are generated, as mentioned during the visit. Figure B.19 shows the ruminal content that is collected in the trucks directly.

Figure 18. **Fat pit**

Figure 19. **Truck with ruminal content**

Finally, there are also remains of meat or viscera (swine intestines, hair, hooves, cattle intestines, confiscated carcasses). During the visit it was mentioned that up to 3 cows are seized per day. These remains are taken to the landfill. In the Figure B.20 is shown the truck with the remains of meat and viscera.

Figure 20. **Truck with meat remains and viscera, currently going to landfill**

Contrary to cattle that requires skin removal, pigs only require skin cleaning and hair removal, that is realized by scalding, for which, it is required to heat water at a temperature of 70°C. For that purpose, solar heaters are used; however, only a temperature of 50°C is reached. So, natural gas is used to achieve the 70°C.

2.2.2. Municipal slaughterhouse of San Francisco del Rincón

The San Francisco del Rincón municipal slaughterhouse is located 3.1 km far from San Jerónimo WWTP, in Teodoro González street, number 0, in Santa María neighborhood, San Francisco del Rincón, Guanajuato, México. Its coordinates are: 20°59’47.96’’ N, 101°51’2.93’’ W. Figure 21 shows the satellite view of the slaughterhouse.

The Figure 22 exhibits the sacrifice area for cattle, where it is observed that part of the blood arrives at the trap along with the washing water. On the other hand, in Figure B.23 it is showed the bleeding area for swine.

Figure 21. **Satellite view of the slaughter of "San Francisco del Rincón"**

Figure 22. Sacrifice area for cattle

Figure 23. Bleeding area for swine

Additionally, in the following Figure (24) it is observed a trap with traces of blood and fat. Each year, more than 330,000 liters of blood are produced, 90% corresponds to the vaccine blood, while the remaining 10% corresponds to pig blood.

In relation to the ruminal content, there is a screw, which not only transports the ruminal content to the truck, but also drains it, since the water stays below, as shown in the Figure B.25. Subsequently, the ruminal content in the truck (Figure B.26) is sent to composting near the slaughterhouse (5-10 km) (without cost for either of the parties). The ruminal content is accompanied by manure.

Two trucks per day are filled with this waste. For each cow of 500 to 1,200 kg, 60 to 70 kg of ruminal content are obtained, while a bullock of less than 400 kg produces 30 to 40 kg of ruminal content.

Figure 24. **Trap with blood and fat**

Figure 25. **Conveyor screw for ruminal content**

Figure 26. **Conveyor screw to the truck (for subsequently composting)**

Regarding the grease, the majority (around 80%) is used to make products such as candles and makeup. On the other hand, from 2 to 3 boats (20 liters per day, approximately) are collected from the grease traps, which is sent to the landfill. Figure 27 shows some of the grease traps in the slaughterhouse.

Apart from the grease, the seizures of meat (from sicked animals) are also sent to the landfill. In average, there are three seizures per day, from organs to entire carcasses.

With respect to other waste, the cow skin is removed and delivered to the producers. The viscera is used for rendering.

Figure 27. **Grease traps in the slaughterhouse**

NOTE: It is probable that slaughterhouses are joined in a new installation.

In summary, the residues from the slaughterhouses are already used for animal feeding, as raw material for candles and cosmetics, and also for composting (even if they do not comply with sanitary regulations). Organic residues that are not used, are just freely disposed into the open dump described previously.

These circumstances make difficult to find suitable organic wastes from slaughterhouses that can be sent to San Jerónimo WWTP. Any kind of residues transportation to the WWTP would be consider an extra-cost for the stakeholders, instead of a benefit.

2.3. Markets

2.3.1. Municipal market of La Purísima del Rincón "Ing. Manuel G. Aranda"

It is located 4.6 km far from San Jerónimo WWTP, on Hermenegildo Bustos street with corner on Manuel Doblado Street, in front of the municipal garden in Purísima de Bustos, Guanajuato. Its coordinates are: 21°1'44.70'' N, 101°52'40.43'' O.

Figure 28. **Satellite view of the Municipal market of Purísima del Rincón "Ing. Manuel G. Aranda"**

There are 35 premises in this market, of which 80% are restaurants (Figure B.29). There are few premises of raw food and other types of shops.

There is a mixture of all types of garbage, which is not separated, and all is sent to the landfill. There are two shifts to transport the garbage: the first at 2 pm and the second from 6 to 7 in the afternoon.

In the week, there is a garbage production of 3 ton/d, while on the weekend, up to 6 ton/d of garbage can be generated.

It was mentioned that the garbage containers include the same type of debris, that is not separated because everything is mixed in the garbage truck. In addition, the percentage of organic waste is unknown.

About the fee for handling trash, there is no exact data because there is a fare ($300/month) for having a restaurant or shop in the market, that includes all services (cleaning, community lighting, handling and transport of waste). Each tenant pays the electricity and water consumed. However, a fare of 100 pesos per ton of municipal origin was mentioned.

Regarding oily waste, the quantity generated is not clear and the destination of theses residues, as mentioned before is not known since part of this residues evaporate.

Figure 29. **General view of the premises in the Municipal market "Ing. Manuel G. Aranda"**

2.3.2. Municipal market of San Francisco del Rincón

It is located 4.0 km far from San Jerónimo WWTP, on Emiliano Zapata Boulevard, 124, Downtown area, San Francisco del Rincón, Guanajuato. Its coordinates are: 21°0'54.35''N, 101°51'31.46'' O.

This market is larger than Purísima del Rincón market. There is a greater variety of commercial activities, from clothing and shoes stalls, to butcheries, groceries and restaurants. In Figures B.30 and B.31 some stalls in the market can be observed.

Regarding garbage, the one coming from fruit and vegetable stores is used for animal feed, which is transported by the beneficiaries. In one of the larger stalls, 10 to 15 baskets are generated (15-20 kg of garbage per day). Figure B.32 shows green garbage collected in buckets to be given to those interested.

Figure 30. **Shops in the market**

Figure 31. **Shops in the market**

Figure 32. **Bucket with organic garbage from groceries**

About butcheries, the waste (grease and bone) are bought by producers from León, Guanajuato. Grease is used to produce makeup and candles, while the bones are used as fertilizer, pet food and toothpaste. A butchery generates 20 to 30 kg of fat per 400 kg of meat sold per day and from 60 to 70 kg of bone is discarded per day and per carcass. Also, it was declared that only a few of the residues generated by the butcheries is discarded in the market containers (which is not sold to the people of León). The fat is sold at 5 pesos per kilogram, while the bones are sold at 1 peso per kilo.

In one of the fish shops it was mentioned that before, their waste was used for animal feed; however, nowadays their waste is disposed in the containers.

The largest amount of organic waste comes from restaurants, only one of the stores gives away their wastes for animal feed. The rest of the stalls throw their waste in the container of the market. It was mentioned that 6 containers (3 m^3, approximately) are filled per day. The containers are filled by all kinds of debris as they are located outside the market and can be accessed by anyone. In Figure B.33 the containers can be observed.

In relation to fats and oils, there is no special container for the collection for this type of waste. In some restaurants, the fats and oils are discarded in bags to the container; however, some just throw the oil into the sink.

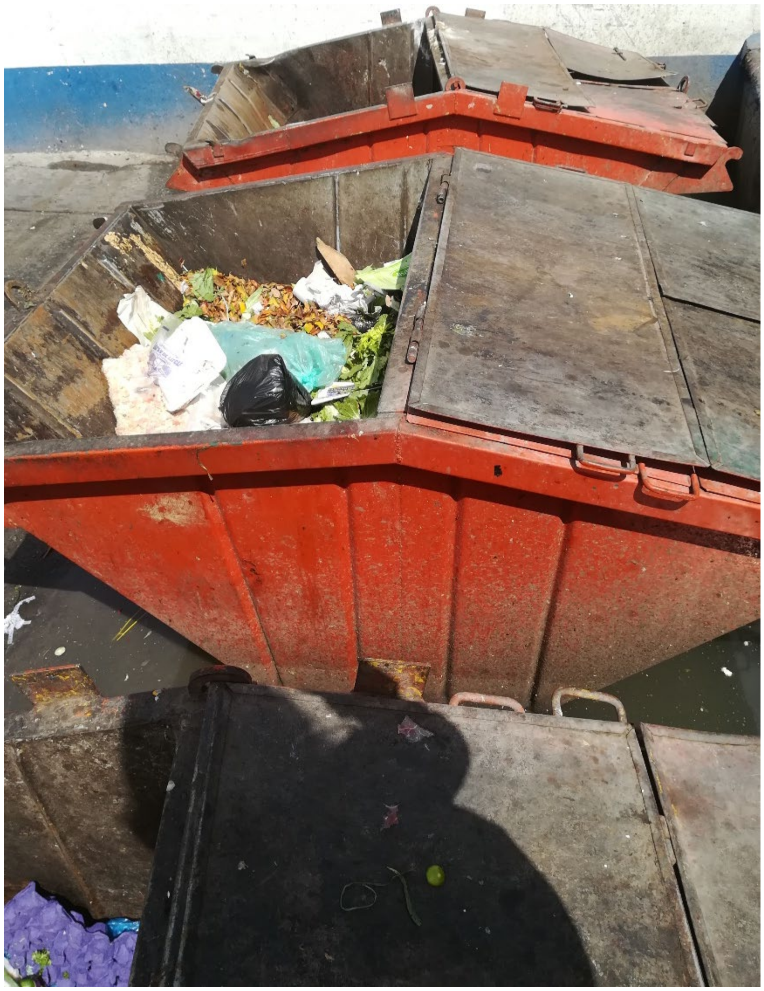

Figure 33. **Waste container from the municipal market of San Francisco.**

Most of organic residues at the markets are already used for animal feeding, which is already an excellent and sustainable solution. The organic residues remaining are dumped and mixed with inorganic residues before its disposal out of the market. There is not any kind of incentives, nor fines, that promote the separation of the residues.

Additionally, FOGs from restaurants are not properly separated and disposed, despite special containers have been installed outside the markets. Owners of the restaurants are not aware of the environmental damage of the FOGs disposed in the sewerage, or the methane generation potential.

These circumstances make difficult to find suitable organic wastes from slaughterhouses that can be sent to San Jerónimo WWTP. Any kind of residues transportation to the WWTP would be consider an extra-cost for the stakeholders, instead of a benefit.

2.4. Dairy industry (Lácteos Jalpa)

The "Lácteos Jalpa" is located 32 km far from San Jerónimo WWTP, at km 3 over the road Purísima Guanajuato-Jalisco. This dairy factory produces different type of cheeses, such as: fresh, ranch, Oaxaca, and "panela". Additionally, this factory produces cream and "cajeta" (caramel).

After the reception of the milk, it is pasteurized in order to ensure product safety. Starter cultures (lactid acid bacteria) are added to start the cheesemaking process. During the fermentation process, rennet (complex set of enzymes produced in the stomachs of ruminant mammals) is added. Consequently, the casein (milk protein) coagulates, precipitates and forms the "cheese curd".

Calcium chloride ($CaCl_2$) is a salt that helps coagulation and is used in cheese making to obtain a firmer curd. In this dairy factory, 2.6 kg of $CaCl_2$ are added to each tank of 4 000L volume. Then, a separation of the liquid (whey) from milk solids (curt) is done. The cheese whey is released and disposed into the factory drainage. The whey discharged is salty and with low pH (4.6 approximately).

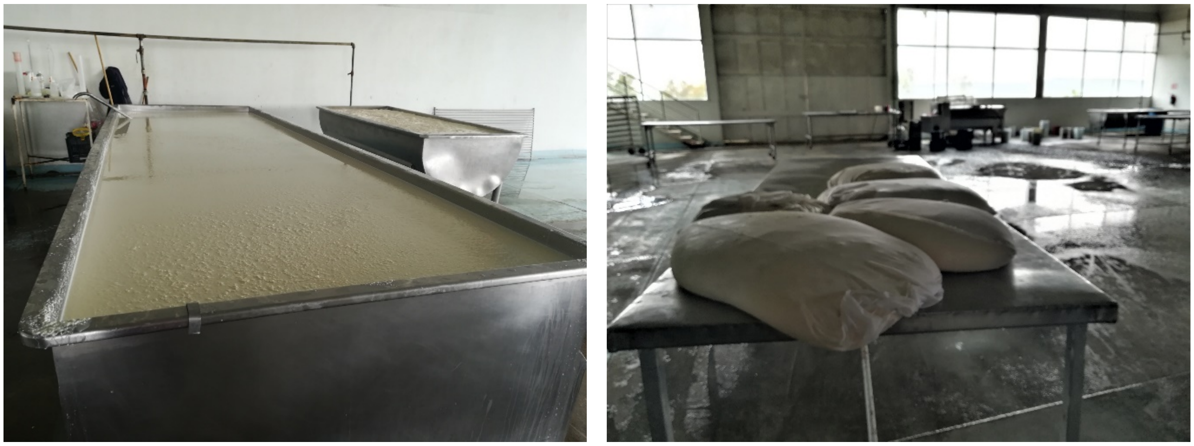

Figure 34. "Quesera Jalpa" facilities: a) Pipe transporting mil into the factory, b) Fermentation and coagulation tank (4 000L) for cheese production, c) Dewatering of cheese curd.

A characterization of a simple sample of the cheese (date unknown) whey is shown below:

Table 3. Cheese whey characterization at "Lácteos Jalpa"

Parameter	Units	Value
pH		5
Conductivity	MS/cm	892
TS	mg/L	75 984
TSS	mg/L	5 880
VSS	mg/L	5 870
COD	mg/L	80 400
Total N	mg/L	2 200
FOGs	mg/L	10 560

This factory does not have access to municipal sewerage, so the industrial wastewater is directed into four grease traps. Every two months, the grease traps are dredged. The overflow from the grease traps goes to an oxidation ditch, with no geomemebrane installed, so wastewater is directly in contact with the soil (clay). The effluent finally flows into an irrigation launder.

Figure 35. Overview of the four grease traps outside “Quesera Jalpa”

Figure 36. FOGs accumulation content inside the grease traps

Figure 37. Oxidation ditch for industrial wastewater

In fact, "Lácteos Jalpa" has already sent cheese whey to San Jerónimo WWTP in order to evaluate the possibility of a co-digestion process. Few tests have been carried-out at the plant, feeding the anaerobic digester with a mixture of cheese whey and WWTP sludge, using a ratio of 1:10. It has been observed a reduction of the methane production in the anaerobic digester. This negative performance could be the consequence of a lack of acclimation of the anaerobic biomass, and/or the inhibition of the anaerobic process due the high salt concentration.

The cost of transporting the cheese why to the WWTP is $14 000 Mexican pesos per month. "Lácteos Jalpa" produces from 30 to 45 m^3 of cheese whey per month.

"Lácteos Jalpa" has a plan for the future that includes the valorization of the cheese whey in order to produce another subproduct called "requesón". The elaboration of this subproduct requires the addition of more salts in order to precipitate the remaining proteins contained in the whey. This will decrease the organic content of the cheese whey (and so the methane potential value) and, at the same time it will increase the salt content in the whey (anaerobic process inhibition).

In conclusion, under the current conditions the use of cheese whey as a feedstock for the anaerobic digester in San Jerónimo WWTP was not feasible. In addition to the probable anaerobic process inhibition, there is any external pressure for “Lácteos Jalpa” to send the cheese whey to other site or to treat it. Currently, the factory can continue discharging into the oxidation pond without paying any kind of fee.

2.5. Agricultural lands

There are some agricultural lands 10 km far from San Jerónimo WWTP sorghum and maize are the main crops cultivated.

San Jerónimo WWTP has been in contact with the farmers in this region in order to use, in the near future, treated wastewater and sludge from the WWTP in the site. Mr. Lorenzo Valadez, the President of the Local Farmers Association at 100 hectares around (“Asociación Civil de Productores de la Galera”), has been testing and using WWTP sludge; he is convinced of the benefits of biosolids use. Nevertheless, farmers awareness and public acceptance is still required, but it is in process.

Mr. Lorenzo is receiving from the WWTP a batch of $7m^3$ of sludge, every week. Firstly, the wet sludge (20% TS aprox.) is spread on the ground. After some days, the sludge is dried by solar radiation; the sludge volume is reduced 4-5 times. Handling of dry sludge is easier, tractors can spread it more gently and homogenously on the soil.

The farmers currently use 0.5-1.0 tons of ammonium sulfate per one hectare (depending if it is rainy or dry season). Ammonium sulfate costs approximately $5 000 Mexican pesos per ton. Other option is to use urea as a fertilizer. The efficiency is double, so the farmers require to spread about 50% compared to ammonium sulfate, but urea cost is higher than $7 000 Mexican pesos per ton. Each hectare in the region produces approximately 7-8 tons of sorghum.

Mr. Lorenzo estimates that if WWTP sludge is used, the farmers would require about twice the mass compared to synthetic fertilizer, which is equivalent to 1-2 tons of WWTP sludge per hectare. The biggest advantage of using WWTP sludge as biosolid is that the nutrients are released slower than the synthetic fertilizers. This slow bioavailability in turn has two main benefits: 1) the time between each fertilizer spreading could be extended, and 2) the leaching of fertilizers into the soil and groundwater can be reduced, so this would help to control eutrophication problem at water bodies (Jen-Hshuan Chen, 2006).

It is important to mention that there is water scarcity in the region, even for the farmers. Environmental protection of the water bodies in the site is important for the society.

Figure 38. Truck with WWTP sludge coming out from the into to the agricultural lands

Figure 39. The President of the Local Farmers Association, convinced that the use of WWTP sludge is the best option to fertilize the crops in the region.

2.6. Municipal landfill

It was not possible to contact the person in charge of the municipal landfill. Nevertheless, during the visit to the site, it was observed that this landfill is, in reality, an uncontrolled open dump. There is no separation of the residues, no geomembrane over the soil preventing leachates filtration, no sanitary control, and there are methane emissions into the environment. An important amount of residues coming from textile industry was observed.

According to the Ecology Institute in the State of Guanajuato (IEE), the municipality of Purísima del Rincón generates 47 tons per day of urban residues and 52.5 tons per day of residues that required special management according to the Mexican regulation. The figures above is equivalent to 0.38 kg of residues per habitant per day. Approximately 30% of residues are organic matter.

IEE has a plan for the future installation of a new municipal landfill that complies with NOM-083-SEMARNAT-2003.

Figure 40. Open dump in Purísima del Rincón.

Figure 41. Open dump in Purísima del Rincón.

3. PRE-FEASIBILITY STUDY

3.1 Technical pre-evaluation

3.1.1 No biogas project

Unfortunately, it was not possible to find a feasible option for a biogas project in Guanajuato under the current framework conditions. I was not possible to find suitable available organic waste streams that were logistically possible to use for biodigestion at the WWTP.

Most of organic residues at the markets are already used for animal feeding, which is already an excellent and sustainable solution. The organic residues remaining are dumped and mixed with inorganic residues before its disposal out of the market. There is not any kind of incentives, nor fines, that promote the separation of the residues. A separation could be established but the amounts are too small to make a positive business case if the WWTP has to pay extra costs for separation and transportation.

Additionally, FOGs from restaurants are not properly separated and disposed, despite special containers have been installed outside the markets. Owners of the restaurants are not aware of the environmental damage of the FOGs disposed in the sewerage, or the methane generation potential.

Additionally, the residues from the slaughterhouses are already used for animal feeding, as raw material for candles and cosmetics, and also for composting (even if they do not comply with sanitary regulations).

Organic residues that are not used, are just freely disposed into the open dump described previously. Consequently, saved landfill costs cannot be included in the business case.

This is a very unfortunate situation, considering the valuable possibility of the biogas and electricity generation, using the existing facility of San Jerónimo WWTP.

3.1.2 Opportunity areas at San Jerónimo WWTP

Some areas of opportunity were found during the analysis of the performance of biogas use in San Jerónimo WWTP.

Under the current situation, the CHP only operates 3-4 hrs per day (average), and the working load is just 65%, whereas the recommended load is 90%. The problem is that, when working load of the

CHP is low, its efficiency is poor. As a result, the electrical efficiency of the CHP is approximately 25%, whereas the installed CHP could reach an electrical efficiency of 39%, according to Guascor (supplier). Consequently, the electricity generation from the biogas is just 1.3 kWh per m^3 of biogas, although it could reach a value of 1.86 kWh per m^3 of biogas under an optimum scenario.

Additionally, the low working load of the CHPs diminish the thermal energy obtained from the cooling of the jacket, so it is not enough to heat the digester. Heat from combustion gases is not recovered either. Therefore, 50% of biogas should be supplied directly into the boiler in order to heat the anaerobic digester.

On top of that, 10% of the biogas is just burned in the flare.

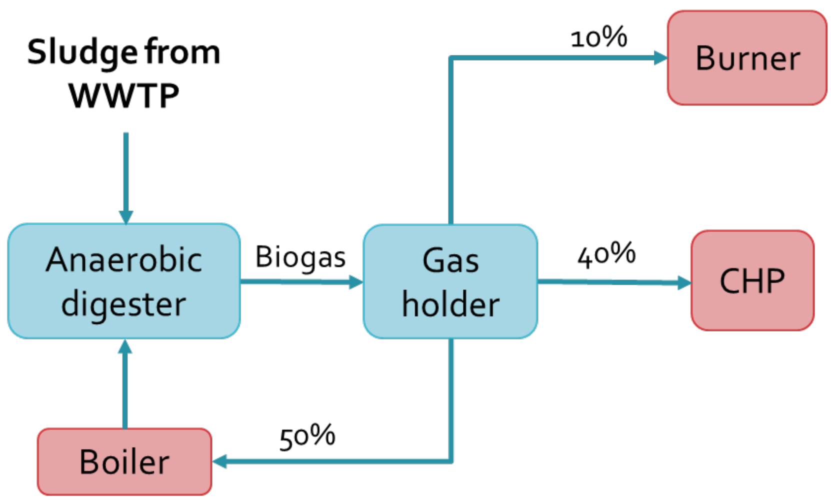

Figure 42. Current situation of biogas use in San Jerónimo WWTP

There are opportunities to increase electricity production by changing the current means of biogas use, without using additional feedstock, such as:

1. **Increasing working load from 65% to 90%**

If the working load of the CHP is increased up to 90% (as recommended by the manufacturer), the electrical efficiency could reach 35-39%, so the electricity production in CHP could increase to 1.86 kWh per m^3 of biogas.

2. **Use of thermal energy from cooling of jacket and combustion gases in order to heat the digester.**

This would reduce the biogas used directly in the boiler to heat the anaerobic digester.

3. **No biogas is burned.**

This would increase the biogas used in the CHP.

Under this recommended scenario, the CHP would still operate about 3.5 hours but the electricity production would increase. By upgrading the current conditions of CHP operation (no co-digestion included so far), there could be additional savings of **approximately USD$ 14,000/year.**

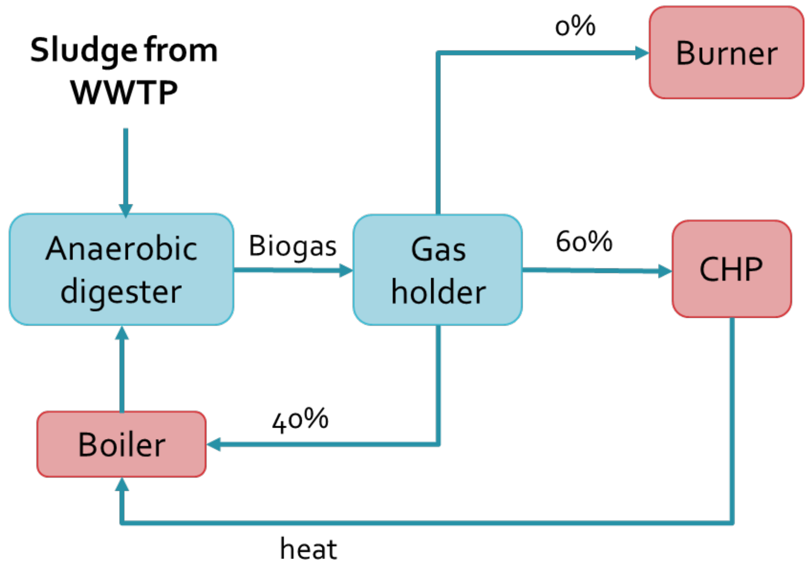

Figure 43. Recommended situation of biogas use in San Jerónimo WWTP

Unfortunately, if the recommendations described above are implemented under current conditions, the kWh/h produced would exceed the electricity demand in the WWTP. It is difficult that the surplus energy is sold to the grid,although it is possible, it is an expensive and complicated legal procedure (see ANNEX 3- REGULATIONS FOR SELLING ELECTRICITY INTO THE GRID IN MEXICO) . Consequently, the recommendations given could be a good option for a future scenario, when the capacity of the WWTP is increased up to the design flow, and the plant has a higher electricity demand as a result.

3.2 Conclusions

3.2.1 Lessons learned

- **LEGISLATION FRAMEWORK**.

Selling electricity to the grid is an expensive and complicated legal procedure.

Co-digestion projects could be easier and more feasible if the legislation obligates the:

- Separation of residues.
- Appropriate separation and disposal of FOGs from restaurants.
- Safely reuse/disposal of wastes from slaughterhouse.

It is recommendable that Guanajuato government analyze some other strategies for residues management. The approach in the State is still the disposal of residues into landfills, instead of a circular economy in which residues are valorized.

- **PUBLIC ACCEPTANCE**

It is remarkable to notice that in at the State, farmers are very accustomed to use untreated raw wastewater for crops irrigation. Nevertheless, using treated wastewater and stabilized sludge from WWTP is a better, new, and feasible option but unfortunately it is not broadly accepted yet. Education and awareness of the society is urgent and necessary.

3.2.2 Following steps

- Searching of other feedstocks available in the municipalities of Purísima and San Francisco del Rincón for a potential co-digestion project at San Jerónimo WWTP. Currently, it seems that some industrial wastewater from beverage companies (Jugos del Valle and Nestlé) could be disposed into San Jerónimo WWTP because the existing industrial WWTP in site does not have the capacity to deal with the current and future discharges.
- Education of the farmers and community regarding the benefits of using wastewater and sludge coming from the WWTP into the agricultural lands.
- Review of the legal incentives in the State in order to promote separation of residues, as well as appropriate disposal of FOGs from restaurants and industrial wastes.Review at the State level of the landfill project in order to find more sustainable solutions, such as valorization of residues

BIBLIOGRAPHY

Acuerdo que establece las particularidades técnicas y las fórmulas para la aplicación de metodologías para el cálculo de emisiones de gases o compuestos de efecto invernadero. (2015, septiembre 3). *Diario Oficial de la Federación*. Mexico City, Mexico. Recuperado de http://www.semarnat.gob.mx/sites/default/files/documentos/cicc/acuerdo_que_establece_las_particularidades_tecnicas_y_las_formulas_para_la_aplicacion_de_metodologias.pdf

ACUERDO que establece los gases o compuestos de efecto invernadero que se agrupan para efectos de reporte de emisiones, así como sus potenciales de calentamiento. (2015, agosto 14). *Diario Oficial de la Federación*. Ciudad de México, Mexico.

Belœil, PA., Chauvin C., Fablet C., Jolly J.P., Eveno E., Madec F., Reperant J.M. (2003) Helminth control practices and infections in growing pigs in France. Livestock Production Science 81(1):99-104 · May 2003. DOI: 10.1016/S0301-6226(02)00192-6

Cámara de Diputados del H. Congreso de la Unión (2014), Ley de la Industria Eléctrica. Diario Oficial de la Federación (11/08/2014). http://www.diputados.gob.mx/LeyesBiblio/pdf/LIElec_110814.pdf

CENACE (2015). Criterios mediante los que se establecen las características específicas de la infraestructura requerida para la interconexión de centrales eléctricas y conexión a centros de carga. Centro Nacional de Control de Energía (presentación junio 2015)

Certificados de Energías Limpias. (2016). Retrieved April 29, 2019, from https://www.gob.mx/cre/acciones-y-programas/certificados-de-energias-limpias-51673
CONACCA- Cámara Nacional De Centrales De Abastos. (2018). Directorio Nacional. Retrieved fromhttp://www.conacca.mx/Index.Php/Styles/Centrales-De-Abasto

COMISIÓN ESTATAL DELAGUA DE GUANAJUATO. (2012). *COBERTURA DE SANEAMIENTO DE AGUAS RESIDUALES URBANO-DOMÉSTICAS EN CABECERAS MUNICIPALES DEL ESTADO DE GUANAJUATO*. Retrieved from http://strc.guanajuato.gob.mx/templates/COMUNICACION/LIBROSBLANCOS/CEAG/LB_CEAG_SOC_Cobertura de Saneamiento de Aguas Residuales Urbano - Domésticas_4.pdf

CRE (2017). Factor de emisión del Sector Eléctrico Nacional. Comisión Reguladora de Energía. https://www.gob.mx/cms/uploads/attachment/file/304573/Factor_de_Emisi_n_del_Sector_El_ctrico_Nacional_1.pdf

DEA, Ea Energy Analyses, and IBTech(2019). Biogas plants in Denmark and Mexico. Danish Energy Agency, Ea Energy Analyses and IBTech®.

ENRES, 2017. *Guía técnica para el manejo y aprovechamiento de biogás en plan-tas de tratamiento de aguas residuales*. México: Cooperación Alemana al Desarrollo Sustentable (GIZ México); Asociación Nacional de Empresas de Agua y Saneamiento (ANEAS); Dirección General de Energías Limpias (SENER); Dirección General de Fomento Ambiental, Urbano y Turístico (SEMAR-NAT).

Excélsior (04/12/2018). Por cambio de gobierno suspenden cuarta subasta eléctrica. Periódico https://www.excelsior.com.mx/nacional/por-cambio-de-gobierno-suspenden-cuarta-subasta-electrica/1282549

Generación distribuida. (2017). Retrieved April 29, 2019, from https://www.gob.mx/cre/articulos/generacion-distribuida-102284

Gobierno del Estado de Guanajuato. (2014). Programa Estatal para la Prevención y Gestión Integral de Residuos del estado de Guanajuato.

Instituto de Ecología del Estado de Guanajuato. (2012). Indicadores Clave. Retrieved May 3, 2019, fromhttps://smaot.guanajuato.gob.mx/sitio/micro/siaseg/residuos.php

Instituto Nacional de Estadística y Geografía. (2016). Actividades económicas. Guanajuato. Retrieved May 3, 2019, from http://www.cuentame.inegi.org.mx/monografias/informacion/gto/economia/default.aspx?tema=me

Instituto Nacional de Estadística y Geografía. (2017). Anuario Estadístico y Geográfico de Guanajuato 2017. Aguascalientes. Retrieved from https://www.datatur.sectur.gob.mx/ITxEF_Docs/GTO_ANUARIO_PDF.pdf

International Renewable Resources Institute of Mexico. (2015). Anaerobic biodigester technology in methane capture and manure management in Mexico. USAID.

Jen-Hshuan Chen. The combined use of chemical and organic fertilizers and/or biofertilizer for crop growth and soil fertility. Department of Soil and Environmental Sciences, National Chung Hsing University, Taiwan, R.O.C. International Workshop on Sustained Management of the Soil-Rhizosphere System for Efficient Crop Production and Fertilizer Use (16 – 20 October 2006) Land Development Department, Bangkok 10900 Thailand. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.474.2251&rep=rep1&type=pdf

Jimenez B., Maya C., Galván M., (2017). Helminth ova control in wastewater and sludge for advanced and conventional sanitation. Water Science & Technology. February 2007. DOI: 10.2166/wst.2007.046

Jiménez-Cisneros B.E., Maya-Rendón C. and Salgado-Velázquez G., (2001) The elimination of helminth ova, faecal coliforms, Salmonella and protozoan cysts by various physicochemical processes in wastewater and sludge. Water Science and Technology Vol 43 No 12 pp 179–182

Ley de la Industria Eléctrica. (2014, August 11). *Diario Oficial de la Federacion*. Mexico City, Mexico.

NORMA Oficial Mexicana NOM-083-SEMARNAT-2003, Especificaciones de protección ambiental para la selección del sitio, diseño, construcción, operación, monitoreo, clausura y obras complementarias de un sitio de disposición final de residuos sólidos urbanos y de manejo especial. (2004). Diario Oficial de la Federación. Retrieved from https://www.profepa.gob.mx/innovaportal/file/1306/1/nom-083-semarnat-2003.pdf

Plataforma informática en materia de Generación Distribuida de CFE Distribución. (2019). Retrieved from http://app.distribucion.cfe.mx/Aplicaciones/GeneracionDistribuida/

PROYECTO de Modificación de la Norma Oficial Mexicana NOM-001-SEMARNAT-1996, Que establece los límites máximos permisibles de contaminantes en las descargas de aguas residuales en aguas y bienes nacionales para quedar como proyecto de modificación de la Norma Oficial Mexicana PROY-NOM-001-SEMARNAT-2017, Que establece los límites permisibles de contaminantes en las descargas de aguas residuales en cuerpos receptores propiedad de la nación http://www.dof.gob.mx/nota_detalle.php?codigo=5510140&fecha=05/01/2018

Regattieri, A., et al (2018) Biogas Micro-Production from Human Organiz Waste- A Research Proposal. Sustainability MDPI
https://www.mdpi.com/2071-1050/10/2/330

SADER y SENASICA (2019). Directorio de establecimientos tipo inspección federal autorizados, vigentes. Secretaría de Agricultura y Desarrollo Rural; Servicio Nacional de Sanidad, Inocuidad y Calidad Alimentario. Retrieved fromhttps://www.gob.mx/cms/uploads/attachment/file/457131/Directorio_TIF_26-04-2019.pdf

SADER y SENASICA (2019). Listado de rastros y/o centros de matanza en los que se realiza vigilancia o seguimiento operativo por parte de las entidades federativas año 2019. Secretaría de Agricultura y Desarrollo Rural; Servicio Nacional de Sanidad, Inocuidad y Calidad Alimentario. Retrieved from https://www.gob.mx/cms/uploads/attachment/file/448728/DIRECTORIO_RASTROS_280319.pdf

SEMARNAT (2016). Guía de usuario Registro Nacional de Emisiones (RENE). Cooperación Alemana al Desarrollo (GIZ) y Secretaría de Medio Ambiente y Recursos Nacionales (SEMARNAT)
http://www.semarnat.gob.mx/sites/default/files/documentos/cicc/20160623_guia_rene.pdf

SEMARNAT (2010). *Programa Nacional de Remediación de Sitios Contaminados*. Ciudad de México. Secretaría de Medio Ambiente y Recursos Naturales. Retrieved from http://biblioteca.semarnat.gob.mx/janium/Documentos/Ciga/Libros2011/CD000953.pdf

SEMARNAT (2019). *Sitios potencialmente contaminados y sitios contaminados registrados en el SISCO como pasivos ambientales*. Secretaría de Medio Ambiente y Recursos Naturales. Retrieved from http://dgeiawf.semarnat.gob.mx:8080/ibi_apps/WFServlet?IBIF_ex=D3_SITIOS03_01&IBIC_user=dgeia_mce&IBIC_pass=dgeia_mce&NOMBREENTIDAD=*

SENER, DEA, IBTech, Clúster de biocombustibles gasesos, II-UNAM (2018) Feedstock database for biogas in Mexico.

Unidad de Transparencia y Archivos del Poder Ejecutivo del Estado de Guanajuato. (2017). *Solicitud de acceso a la información 00195617*. Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwj_zJSixYDiAhUdJjQIHcoHCoQQFjAAegQIABAC&url=https%3A%2F%2Ftransparencia.guanajuato.gob.mx%2Fdedalo%2Fmodulos%2Fbajaarchivo.php%3Ftipo%3D1%26archivo%3D28597%2Frespuesta_28597.pdf&usg

ANNEX

ANNEX 1 – MEXICAN NORMATIVITY REGARDING WASTEWATER AND SLUDGE

WASTEWATER FOR IRRIGATION

The most updated version of this official norm is the project of norm **PROY-NOM-001-SEMARNAT-2017**, which would be implemented soon in Mexico. This norm establishes the maximum permissible limits of pollutants in wastewater discharges into national waters bodies. According to this standard, the most important limits to comply are:

		Monthly average	Daily average	Instantaneous value
Temperature	°C	35	35	35
Fats and oils	mg/L	15	18	21
TSS	mg/L	100	120	140
COD	mg/L	150	180	210
COT	mg/L	38	45	53
Total nitrogen	mg/L	NA	NA	NA
Total phosphorus	mg/L	NA	NA	NA
Helminth eggs	eggs/L	1	1	1
Escherichia coli	MPN/100mL	1 000	1 200	1 400
pH		6.5-8.5	6.5-8.5	6.5-8.5
True color		Purity 50%	Purity 50%	Purity 50%
Acute toxicity	(UT)	<=5	<=5	<=5
Arsenic	mg/L	0	0.3	0.4
Cadmium	mg/L	0.2	0.3	0.4
Cyanide	mg/L	1	2	3
Chromium	mg/L	1	1.25	1.5
Mercury	mg/L	0.01	0.015	0.02

NIquel	mg/L	2	3	4
Lead	mg/L	0.2	0.3	0.4
Zinc	mg/L	10	15	20

WASTEWATER FOR DISCHARGING INTO THE MUNICIPAL SEWERAGE

The **NOM-002-SEMARNAT-1996** establishes the maximum permissible limits of pollutants of wastewater discharges into urban or municipal sewage. The most important limits specified are:

		Monthly average	Daily average
Temperature	°C	<40	<40
Fats and oils	mg/L	50	75
TSS	mg/L	150	200
BOD	mg/L	150	200
pH		10-5.5	10-5.5
Floating matter		Absence	Absence
Total Arsenic	mg/L	0.5	0.75
Total Cadmium	mg/L	0.5	0.75
Total Cyanide	mg/L	1	1.5
Total Copper	mg/L	10	15
Total Chromium	mg/L	0.5	0.75
Total Mercury	mg/L	0.01	0.015
Total Niquel	mg/L	4	6
Total Lead	mg/L	1	1.5
Total Zinc	mg/L	6	9

SLUDGE

The **NOM-004-SEMARNAT-2002** specifies the maximum permissible limits of pollutants in the sludge and biosolids in order to be used for soil improvement. According to this norm, the biosolids should comply with the following parameters depending on the quality of sludge (A, B, or C):

Table. Classes of sludge (NOM-004-SEMARNAT-2002)

TYPE	CLASS	USE
EXCELLENT	A	Public uses with directly contact Uses for classes B & C
EXCELLENT OR GOOD	B	Public uses without directly contact Uses for class C
EXCELLENT OR GOOD	**C**	**Forest, agricultural uses and for soil improvement (fertilizer)**

Table. Biosolids parameter (NOM-004-SEMARNAT-2002)

Class	Bacteriologic indicator	Pathogens	Parasites
	Faecal coliforms (MPN/g dry weight)	**Salmonella spp. (MPN/g dry weight)**	**Helminth eggs/ g dry weight**
A	< 1 000	< 3	< 1 (viable)
B	< 1 000	< 3	< 10
C	< 2 000 000	< 300	< 35

Table. Metals limits in biosolids according to NOM-004-SEMARNAT-2002

Metal	Excellent	Good
	mg/kg (dry weight)	**mg/kg (dry weight)**
Arsenic	41	75
Cadmium	39	85
Chromium	1 200	3 000
Copper	1 500	4 300
Lead	300	840
Mercury	17	57
Nickel	420	420
Zinc	2 800	7 500

HELMINTH OVA (EGG) ISSUE

In 1989, the World Health Organization (WHO) drew attention to diarrhoeal diseases caused mainly by helminths present in sludge and wastewater and set guidelines for safe reuse. Helminthiases are particularly common in regions where poverty and poor sanitary conditions are dominant, like Africa, Latin-America and the Far East. Helminths are pluri-cellular worms that reproduce through ova (eggs). Helminthiases are acquired through ingestion of polluted crops or meat, and contact with faeces, wastewater or contaminated soil (Jimenez B., *et al*., 2007).

When a person ingests infectious eggs, they adhere to the duodenum where the larva leaves the shell, crossing the intestinal wall into the bloodstream. Through the blood, Ascaris (the most frequent Helminthiases) travels to the heart, lungs and bronchial tubes where it breaks the walls, remaining around 10 days in the alveolus. Then it travels to the trachea from where it is ingested, again returning to the intestine, where it reaches its adult phase and, once mated, the female produces up to 200 000 eggs per day. During its migration Ascaris may cause fever, urticaria and asthma; it may encyst in kidney, bladder, appendix, pancreas or liver, and its presence in the intestine produces abdominal pain, meteorism, nausea, vomiting, diarrhoea and undernourishment. In general, the infective agents are the eggs, not the worms. Worms cannot live in wastewater or sludge because they need a host. Therefore, part of the control strategy for helminthiasis is to remove the eggs from wastewater and inactivate them in the sludge produced from wastewater treatment. Helminth ova can remain viable in water, soil and crops for several months/years (WHO, 2006).

Not all wastewater and sludge contain significant amounts of helminth ova. For this reason, they are not included in all countries' wastewater regulations or in all sludge revalorisation options. Regarding pig slurry, helminth eggs can be somewhat controlled by hygienic measure, but parasites may be still present in indoor intensive pig operations (Belœil, PA., et al., 2003).

ANNEX 2 – ELECTRIC TARIFF SCHEME IN MEXICO

In March of last year, the new tariff scheme of the Federal Electricity Commission (CFE) came into force. Since the introduction of the energy reform, the Energy Regulatory Commission (CRE) oversees the definition of electricity rates, a task that was previously carried out by the CFE.

The purpose of the new tariff scheme is to promote the efficient development of the electricity industry, in which prices are based on the costs of production and distribution of electric service. To the above, the costs of fossil fuels used to generate electricity are added, it should be noted that these costs vary month by month.

With this scheme, the electricity receipts break down the price into: transmission, distribution, CENACE (National Center for Energy Control) operation, basic supply operation, related services not included in the MEM (Wholesale Electricity Market), generation costs and capacity. The structure was changed in view of the fact that in the future there will be energy generating companies that will sell energy.

The users were grouped according to their consumption characteristics, the voltage level to which they are connected and the type of measurement they have. In this way, the following twelve rate categories are established and their correspondences to the previous rate are also presented:

Table. Rate categories

Rate category:	Description	Previous rate
DB1	Domestic Low Voltage, consuming up to 150 kWh/month.	1, 1A, 1B, 1C, 1D, 1E, 1F
DB2	Domestic Low Voltage, consuming more than 150 kWh/month.	1, 1A, 1B, 1C, 1D, 1E, 1F, DAC
PDBT	Small Demand (up to 25 kW/month) in Low Voltage.	2,6
GDBT	Great Demand (greater than 25 kWh/month) in Low Voltage.	3,6
RABT	Agricultural irrigation in Low Voltage.	9, 9CU, 9N
APBT	Public Lighting in Low Voltage.	5, 5A
APMT	Public Lighting in Medium Voltage	5, 5A
GDMTH	Great Demand (greater than 25 kWh-month) in Horary Medium Voltage.	HM, HMC, 6
GDMTO	Great Demand (greater than 25 kWh-month) in Ordinary Medium Voltage.	OM, 6
RAMT	Agricultural Irrigation in Medium Voltage.	9M, 9CU, 9N
DIST	Industrial Demand in Sub transmission.	HS, HSL
DIT	Industrial Demand in Transmission.	HT, HTL

In each rate category, fixed (per user) and variable (capacity and generation) charges are defined, which reflect the cost nature in each component of the Basic Supply Final Rates (TFSB) and are adapted to the characteristics of consumption and measurement of each user.

Final rate components of the basic supply are:

Supply charge: Fixed charge, independent of the amount of consumption or demand of the user.

Distribution: Cost for distributing electricity through the CFE infrastructure. The distribution rates apply only to users in medium and low voltage, based on the following:

a) For the APBT and RABT rate categories, the charge indicated for the PDBT category will be applied.
b) For the GDMTH, GDMTO, APMT and RAMT rate categories the designated charge for the GDMT category will apply.

Transmission: Charge for the conduction of electrical energy from the generation plants to the delivery point for distribution. The transmission charges are applied per kWh corresponding to the loads and are determined by the voltage level:

a) Categories DB1, DB2, PDBT, GDBT, APBT, RABT, APMT, RAMT, GDMTO, GDMTH and DIST cover the amount corresponding to the voltage level below 220 kV.
b) The DIT category covers the amount for voltages greater than or equal to 220 kV.

CENACE: Charge performed by the National Center for Energy Control (CENACE). The operating charge of CENACE is applied in all rate categories, through an amount per level of consumption (kWh) corresponding to the charges.

Generation: It consists of an energy charge and a capacity charge:

I. **Energy**: It is established by a single variable amount for those categories with simple measurement and with charges for the base, intermediate, peak and semi-peak horary periods corresponding to each rate division, for the categories with hourly measurements.
   a. Categories with unique charge for energy: DB1, DB2, PDBT, GDBT, RABT, RAMT, GDMTO, APBT and APMT.
   b. Categories with charge for hourly energy: GDMTH, DIST and DIT.

II. **Capacity**: They are applied based on the following:
   a. Categories with charge assigned to consumption (kWh): DB1, DB2, PDBT, APBT, APMT and RABT.
   b. Categories with charge assigned to the maximum demand (kW): GDBT, GDMTO and RAMT.
   c. Categories with charge assigned to the maximum demand coinciding with the peak hour period (kW).

SCnMEM: Corresponds to other costs related to the Wholesale Electricity Market. The charge for Related Services not included in the MEM is 0.0054 pesos/kWh and will be applicable for the 12 rate categories and 17 rate divisions. Once the corresponding rate regulation has been established, the charge must refer to the document issued for that purpose.

PARAMETERS

i. Horary periods
ii. Load factors
iii. Loss factors

Horary periods:

a) The base, intermediate, peak and semi-peak horary periods are established in the categories with hourly measurements, in order to perform a differentiated charge according to the period in which the cost of generation is higher.
b) The horary periods are assigned in each of the three systems: Baja California Interconnected System (BC), Baja California Sur Interconnected System (BCS) and National Interconnected System (SIN).
c) In the BC ad BCS systems, the rate divisions of the same name will correspond to each one of them; in the SIN system the rest of the divisions will correspond.
d) The seasons of the year in each of the systems for which the horary periods are defined, will be as follows:

Table. Seasons of the year.

System	Rate category	Season	Period
Baja California	GDMTH, DIST and DIT	Summer	From May 1 to Saturday before the last Sunday of October.
		Winter	From the last Sunday of October to April 30.
Baja California Sur	GDMTH, DIST and DIT	Summer	From the first Sunday of April to the Saturday before the last Sunday of October.
		Winter	From the last Sunday of October to the Saturday before the first Sunday of April.
SIN	GDMTH	Summer	From the first Sunday of April to the Saturday before the last Sunday of October.
		Winter	From the last Sunday of October to the Saturday before the first Sunday of April.
	DIST and DIT	Spring	From the first of February to the Saturday before the first Sunday of April.
		Summer	From the first Sunday of April to July 31.
		Fall	From the first of August to the Saturday before the last Sunday of October.
		Winter	From the last Sunday of October to January 31.

e) The base, intermediate, peak, and semi-peak horary periods are defined for the BC, BCS and SIN systems according to the different times of the year, as follows (only the schedules for the GDMTH rate will be presented, since it is the most common in the industrial and commercial sectors):

Table. Category GDMTH

Interconnected System Baja California			
Summer season			
Weekday	Base	Intermediate	Peak
Monday to Friday		0:00 – 14:00 18:00 – 24:00	14:00 – 18:00
Saturday		0:00 – 24:00	
Sunday and festive		0:00 – 24:00	
Winter season			
Weekday	Base	Intermediate	Peak
Monday to Friday	0:00 – 17:00 22:00 – 24:00	17:00 – 22:00	
Saturday	0:00 – 18:00 21:00 – 24:00	18:00 – 21:00	
Sunday and festive	0:00 – 24:00		
Interconnected System Baja California Sur			
Summer season			
Weekday	Base	Intermediate	Peak
Monday to Friday		0:00 – 12:00 22:00 – 24:00	12:00 – 22:00
Saturday		00:00 – 19:00 22:00 – 24:00	19:00 – 22:00
Sunday and festive		0:00 – 24:00	
Winter season			
Weekday	Base	Intermediate	Peak
Monday to Friday	0:00 – 18.00 22:00 – 24:00	18:00 – 22:00	
Saturday	0:00 – 18:00 21:00 – 24:00	18:00 – 21:00	
Sunday and festive	0:00 – 19:00 21:00 – 24:00	19:00 – 21:00	
National Interconnected System			
Summer season			
Weekday	Base	Intermediate	Peak
Monday to Friday	0:00 – 6:00	6:00 – 20:00 22:00 – 24:00	20:00 – 22:00
Saturday	0:00 – 7:00	7:00 – 24:00 19:00 – 24:00	
Sunday and festive	0:00 – 19:00	19:00 – 24:00	
Winter season			
Weekday	Base	Intermediate	Peak
Monday to Friday	0:00 – 6:00	6:00 – 18:00 22:00 – 24:00	18:00 – 22:00
Saturday	0:00 – 8:00	8:00 – 19:00 21:00 – 24:00	19:00 – 21:00
Sunday and festive	0:00 – 18:00	18:00 – 24:00	

ANNEX 3 – REGULATIONS FOR SELLING ELECTRICITY INTO THE GRID IN MEXICO

Projected or operating biogas plants in Mexico are eligible to obtain profits from electricity generated on-site. The plant has to comply with specific regulations that depend upon the actual or projected installed capacity.

Special formalities apply for any biogas project; in Mexico, they may depend upon the federal, state of municipal (borough) jurisdiction. Prior to the Construction, the Engineering phase of the project require (under Federal State and Municipal Law):

1. Environmental Impact Assessment
2. Zoning modifications
3. Environmental Risk Assessment for the use of hazardous materials
4. Social Impact Assessment

Energy formalities are solved at the federal level, unless otherwise required by State Law.

Centralized power generation apply for any plant able to generate more than 500 kW; the electric generation permit is requested to the Mexican Energy Regulatory Commission (CRE - Comisión Reguladora de Energía), as those plants are the only that require a mandatory permit to construction, start-up, commissioning and operating as stated by the 17th Article (Artículo 17) of the Electric Industry Law ("Ley de la Industria Eléctrica," 2014). The CRE is responsible for assigning, modifying, revoking, cancelling, transferring, delaying and terminating all the permits, as stated by the 12th Article (Artículo 12) of the Electric Industry Law ("Ley de la Industria Eléctrica," 2014). The power plants participate in the Mexican Wholesale Energy Market, complying with the specific Market Rules published elsewhere.

Distributed generation apply for any plant able to generate less than 500 Kw; under this case, the plant will not require a CRE permit, but an agreement with the "provider" (Suministradores), most likely the main power broker: the Federal Electric Commission (Comisión Federal de Electricidad); the company owns a website for the registration and follow up of the distribuited generation procedure ("Plataforma informática en materia de Generación Distribuida de CFE Distribución," 2019). According to the fraction XXXVIII of the 12th article of the law ("Ley de la Industria Eléctrica," 2014) the CRE is responsible for publishing the regulations of the distributed generation, notwithstanding that the Mexican Energy Secretariat was able to publish them only for the first time ("Generación distribuida," 2017).

Both centralized and distribuited generation power plants are eligible for obtaining Clean Energy Certificates (CEL-Certificados de Energías Limpias), one per each MW generated on-site ("Certificados de Energías Limpias," 2016).