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AND

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INSTITUTE FOR TECHNOLOGY AND RESOURCES MANAGEMENT IN THE TROPICS AND SUBTROPICS

POTENTIAL USE OF DAIRY CATTLE MANURE FOR BIOGAS PRODUCTION

THESIS TO OBTAIN THE DEGREE OF

MAESTRÍA EN CIENCIAS AMBIENTALES

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FOCUS AREA "ENVIRONMENTAL AND RESOURCES MANAGEMENT"

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Abstract

Many studies and international experience suggest anaerobic digestion as a good option for manure treatment that induces several benefits like smell reduction, mitigating GHG emissions, production of good quality organic fertilizer and biogas generation. Biogas is composed mainly of methane, a fuel gas, making it a renewable energy source with multiple uses. Biogas production from animal manure is not a new practice and even though there are several studies to improve these systems efficiency, their use has not been disseminated in Mexico.

The State of San Luis Potosí, does not contribute significantly to the national livestock production in Mexico. However, there are about 531 dairy production units located on the surroundings of its capital San Luis Potosí. Some manure management practices can have negative impacts on the quality of water, air and soils. Certain management conditions stimulate the emission of green house gases (GHG) like methane (CH4).In this research Interviews were carried out on seven of these farms with the objective of collecting information concerning their manure management practices and their energy consumption.

Manure produced by agricultural activities is normally applied as fertilizer to crop lands. On the visited farms however, the manure from the dry lot is sold to brick factories. No specific programs or regulations in terms of manure management systems were identified in public and private institutions related with the livestock sector and the environment. However, with the experience obtained in the field visits, it can be assumed that dry lot is a manure management system common on the region of San Luis Potosí.

In 2008 an energy reform was implemented and several programs have developed to support installation of biogas systems in dairy operations with a livestock population of minimum 300 heads. This excludes small producers, whereas the biggest livestock proportion is distributed on small farms (5 to 20 heads). Here lies a high potential for biogas production. To assess this potential as well as the GHG emissions generated by the current manure management practices, a mathematical model designed by the Climate Action Reserve was applied. The results obtained from the model show a high methane generation potential on the visited production units, which would mean significant energy savings.

Although no biogas systems were located in the municipality of San Luis Potosi, the results obtained by the analysis based on the information collected in the interviews show that there is potential in terms of biogas generation. Electricity generation using biogas is therefore economically feasible due to savings on the area´s dairy farms.

Resumen

Numerosas investigaciones, así como la experiencia internacional señalan a la digestión anaeróbica como un método viable de tratamiento de estiércol que produce además otros beneficios, como la reducción de olores, mitigación de emisiones de GEI, producción de un fertilizante orgánico de alta calidad así como favorecer la generación de biogás. El biogás es una mezcla de gases compuesta principalmente por metano, un gas combustible, lo que hace al biogás una fuente renovable de energía que puede ser destinada para distintos usos. La producción de biogás a partir de excretas animales no es una práctica nueva y aunque las investigaciones para mejorar la eficiencia de los sistemas son numerosas, su uso no se ha generalizado en México.

El estado de San Luis Potosí, no contribuye de manera significativa en la producción pecuaria de México. Sin embargo, existen aproximadamente 531 unidades productoras de leche en las comunidades rurales ubicadas en los alrededores de la ciudad. En esta investigación se efectuaron entrevistas en 7 de estas granjas lecheras con el objetivo de recabar información respecto a sus prácticas de manejo de estiércol y sus consumos de energía.

El estiércol producto de las actividades ganaderas es generalmente utilizado como abono para las tierras de cultivo, pero en las granjas visitadas, el estiércol acumulado en los corrales de engorda es vendido a compañías ladrilleras. Tras efectuar consultas a diversas instituciones, tanto públicas como privadas, relacionadas con la ganadería y el medio ambiente, no se identificaron programas ni regulaciones específicas en cuanto a los sistemas de manejo de estiércol, por lo que tampoco hay información respecto a las prácticas más comunes. Sin embargo, con la experiencia obtenida en las visitas a campo se puede concluir que el corral de engorda es un sistema de manejo común en la región de San Luis Potosí.

Con la entrada en vigor de la reforma energética en el 2008, se han desarrollado programas de apoyo para la instalación de sistemas de biodigestión en operaciones lecheras que cuenten con al menos 300 cabezas de ganado, excluyendo a los pequeños productores, a pesar de que la mayor proporción del ganado se encuentra distribuida en granjas pequeñas (5 a 20 cabezas). Para evaluar el potencial de producción de biogás así como las emisiones generadas por las actuales prácticas de manejo, se utilizó un modelo matemático diseñado por Climate Action Reserve. Los resultados arrojados por el modelo muestran un gran potencial en la generación de metano para las unidades de producción visitadas, lo que significaría ahorros considerables en sus consumos de energía.

Aunque no se detectaron sistemas de biodigestión instalados en el municipio de San Luis Potosí, el resultado de la evaluación basada en los datos obtenidos en las entrevistas muestra potencial en términos de generación de biogás además de factibilidad económica en las granjas lecheras de la zona, por los ahorros que representa el generar electricidad usando biogás.

Zusammenfassung

Viele Studien, sowie die internationale Erfahrung zeigen auf dass anaerobe Ausfaulung eine gute Option zur Behandlung von Dung ist welche mehrere Vorteile mit sich bringt. Diese sind vor allem die Verminderung von Gerüchen, Verhinderung von Treibhausgasemissionen, Herstellung hochqualitativen organischen Düngers sowie die Produktion von Biogas. Biogas besteht hauptsächlich aus Methan, wodurch sich als erneuerbarer Energieträger mehrere Verwendungsmöglichkeiten dafür auftun. Biogas Produktion aus tierischem Dung ist keine neue Praxis, und obwohl es diverse Studien gibt um deren Effizienz zu erhöhen wurde dessen Nutzung in Mexico bisher kaum ermittelt.

Der Bundesstaat San Luis Potosí trägt nicht signifikant zur nationalen Viehproduktion in Mexico bei. Es gibt jedoch in etwa 531 Milchviehbetriebe in der Gegend um die Hauptstadt San Luis Potosí. Einige Praktiken im Dung Management können sich negativ auf die Qualität von Gewässern, Luft und der Böden auswirken. Bestimmte Umstände im Management können den Ausstoß von Treibhausgasen wie Methanfördern. In dieser Forschungsarbeit wurden Interviews auf sieben dieser Bauernhöfe durchgeführt mit dem Ziel Informationen über die dortigen Dung Mangement Praktiken sowie deren Energieverbrauch zu sammeln.

Dung der bei landwirtschaftlichen Aktivitäten ensteht wird für gewöhnlich als Dünger auf die Felder ausgebracht. Auf den besuchten Farmen jedoch wird die gesammelte Gülle an lokale Ziegelsteinfabriken weiterverkauft. Es wurden keine speziellen Programme oder Regeln zum Dung Management bei privaten oder öffentlichen Institutionen die im Bereich Viehhaltung und Umwelt tätig sind festgestellt. Aus den Erfahrungen die während der Feldforschung gesammelt wurden lässt sich jedoch darauf schließen dass die Güllesammlung ein System zum Dung Management darstellt welches häufig in der Region San Luis Potosí anzutreffen ist.

Im jahr 2008 wurde eine Energie Reform eingeführt und mehrere Programme haben sich herauskristallisiert um die Installation von Biogasanlagen in Milchviehbetrieben mit einem minimum von 300 Tieren zu unterstützen. Dies schließt Kleinproduzenten aus, wobei der größte Teil des Viehbestandes auf diese kleinen Bauernhöfe verteilt ist (5 bis 20 Tiere). Hier liegt ein hohes Potential zur Biogas Produktion. Um dieses Potential sowie die Treibhausgasemissionen der derzeitigen Dung Management Praktiken zu ermitteln wurde ein von der Climate Action reserve entwickeltel mathematisches model angewandt. Die Ergebnisse die aus dem Modell gewonnen wurden zeigen ein hohes Potential zur Methanerzeugung auf den besuchten Produktionsstätten, was erhebliche Energieeinsparungen bedeuten würde.

Obwohl sich keine Biogassysteme in Stadtbereich von San Luis Potosí befinden, zeigt die Analyse der in den in den Interviews gewonnenen Daten das Vorhandensein eines Potentials zur Biogaserzeugung. Die Energieerzeugung auf den milchviehbetrieben vor Ort ist durch die Einsparungen dementsprechend wirtschaftlich in der Region.

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List of Abbreviations

CRA	Climate Action Reserve
CFE	Comisión Federal de Electricidad
CO_2 eq.	Carbon Dioxide equivalent
FIRCO	Fideicomiso de Riesgo Compartido
GDP	Gross Domestic Product
GHG	Green House Gas
HP	Horse Power
INEGI	Instituto Nacional de Estadísitca y Geografía
IRRI	Instituto Internacional de Recursos Renovables
IPCC	Intergovernmental Panel of climate Change
kWh	KiloWatt-hour
MCF	Methane Conversion Value
MXN	Mexican Pesos
N	North
NPV	Net Present Value
SAGARPA	Secretaría de Agricultura, Ganadería y Pesca
SEDARH	Secretaría de Desarrollo Agropecuario y Recursos Hidráulicos
SEMARNAT	Secretaría de Medio ambiente y Recursos Naturales
SLP	San Luis Potosí
USD	United States Dollars
VOC	Volatile Organic Compounds
W	West

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1. Introduction

The world has the challenge of duplicating agricultural production in order to guarantee feeding security for the 9,200 millions humans that are anticipated to populate the Earth by 2050. The livestock sector has a crucial role, as it has grown at an unprecedented rate during the past decades due to the increasing demand of livestock products in the world´s economies. Animal products contribute to 15% of total feeding energy and 25% of the diet protein. Available data also shows that poor families (particularly women and children) do not consume enough animal products, while people in developing countries consume too much. Besides its feeding purposes, livestock in essential to agricultural production for all the benefits that provides: it's a source of pulling power for transport and tillage; it consumes crop and food wastes contributing to control bugs and brush; and it produces manure that is used to fertilize soils (FAO, 2009).

Livestock production represents 40% of the world´s agricultural production (FAO, 2009); however, it does not have a big economic impact globally, as it contributed with only 1.4% of the world´s gross domestic product (GDP) in 2005 (LEAD, 2006). In Mexico, livestock production has a share of 22.9% of the total economic activity in the primary sector (agriculture, livestock, and fishery) that generates 5.4% of the national GDP (INEGI, El Sector Alimentario en Mexico, 2009). In spite of its modest contribution in economic terms, livestock production has big social impacts as it provides livelihood support, income and employment to almost one billion people in rural areas. Many people is involved in this sector because they have no other alternative, while in developed countries the number of people engaged in livestock production is reduced continuously (LEAD, 2006). In a study taken over in 14 developing countries, showed that 60% of rural families own livestock (FAO, 2009).

The potential impacts of livestock production on the environment are a fact, affecting air, soil and water quality (Miner, 2000). Sometimes the negative impacts are unbalanced with the economic relevance of the sector (FAO, 2009). One of the major sources of pollution related to livestock production is manure. In terms of air quality, airborne discharges from manure include dust and other particulate matter, reduced gases from anaerobic decomposition and odors (Miner, 2000). Methane emissions are of big concern due to its global warming effects (Moller, 2004).

Manure handling has become a major concern in many countries, where society is becoming increasingly less tolerant of activities that have negative environmental impacts (Van Horn, 1994). Metabolic processes of methanogens lead to CH_4 production at all stages of manure handling (BANR & BEST, 2003). While regulations of pollution control are mainly focused in protecting water quality, some governments have created manuals for good practices in animal feeding operations (AFOs) and specific regulations for manure management, including storage and disposal. Anaerobic digestion to produce biogas is a good alternative to give treatment to both liquid and solid wastes (Carrillo, 2003). Biogas can be captured and used as a fuel, being the most feasible method to recover the energy value from manure on individual farms (Van Horn, 1994).

All first generation biofuels (bioethanol, biodiesel and biogas) are produced from and energy crops as maize and sunflower, creating a competition between energy and food uses for the crops (UNEP, 2009). When using manure as a substrate, something that before was considered a waste serves as an energy source. Manure has commonly been used as a soil fertilizer; however, biogas generation does not compete with this, on the contrary, as anaerobic digestion offers and effective way of managing manure by reducing odors and improving the nitrogen content when compared to fresh manure (Carrillo, 2003; Balat, 2009).

Renewable energy can provide energy access to many people in developing countries that depend on more traditional sources of energy. In rural areas and remote communities, renewable energy technologies such as biogas digesters are already providing basic necessities of modern life, including lighting, cooking, motive power, irrigation and heating (REN 21, 2010).

Until 2010, Mexican government institutions have invested nearly 300 million pesos on a pilot project for the installation of large-scale biogas digesters mainly in pig and dairy farms to generate electricity and participate in Clean Development Mechanisms (CDM) for the reduction in methane emissions (SAGARPA S. d., 2010). Some other institutions and companies are installing small-scale biodigesters using private funds, but there is no information of how many and where these systems have been installed.

2 Case study area

San Luis Potosi is the capital city of San Luis Potosi, one of the 32 federal states of Mexico. The city is located in central Mexico at 22° 09´ 04” N and 100° 58´ 34” W, 363 km to the north-west of Mexico City (INEGI, Mexico en cifras, 2012). The city has an altitude of 1860 meters above sea level.

The city of San Luis Potosi corresponds to one of the 58 municipalities that constitute the State. Due to its proximity to the urbanized area of the capital city, the municipality of Soledad de Graciano Sanchez, located east from San Luis Potosi, has grown until both cities merged into one big city with a total population of almost 1 million inhabitants (772,604 SLP; 267,994 Soledad); nevertheless, each municipality keeps its autonomy and has its own government (INEGI, Mexico en cifras, 2012).

The municipality has a dry climate with an annual precipitation of 359.8 mm; the average annual temperature is 17.4˚C with a maximum of 23.9˚C and a minimum of 10.9˚C (Servicio Meteorológico Nacional, 2010).

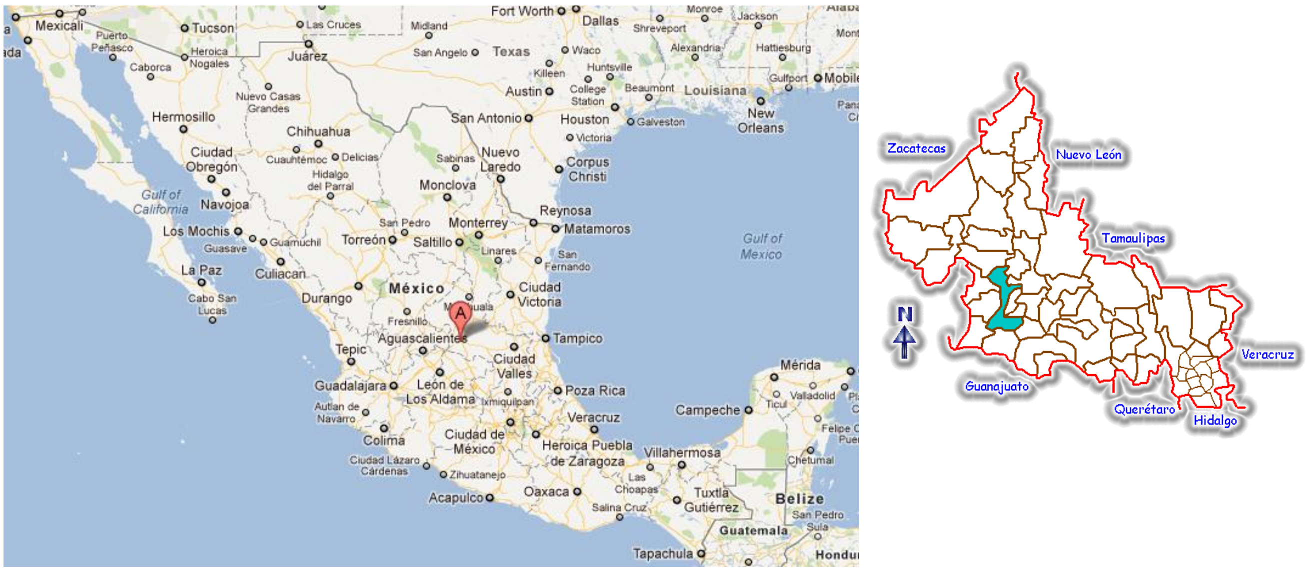

Figure 1 Location of San Luis Potosi a) in Mexico and b) in San Luis Potosi State

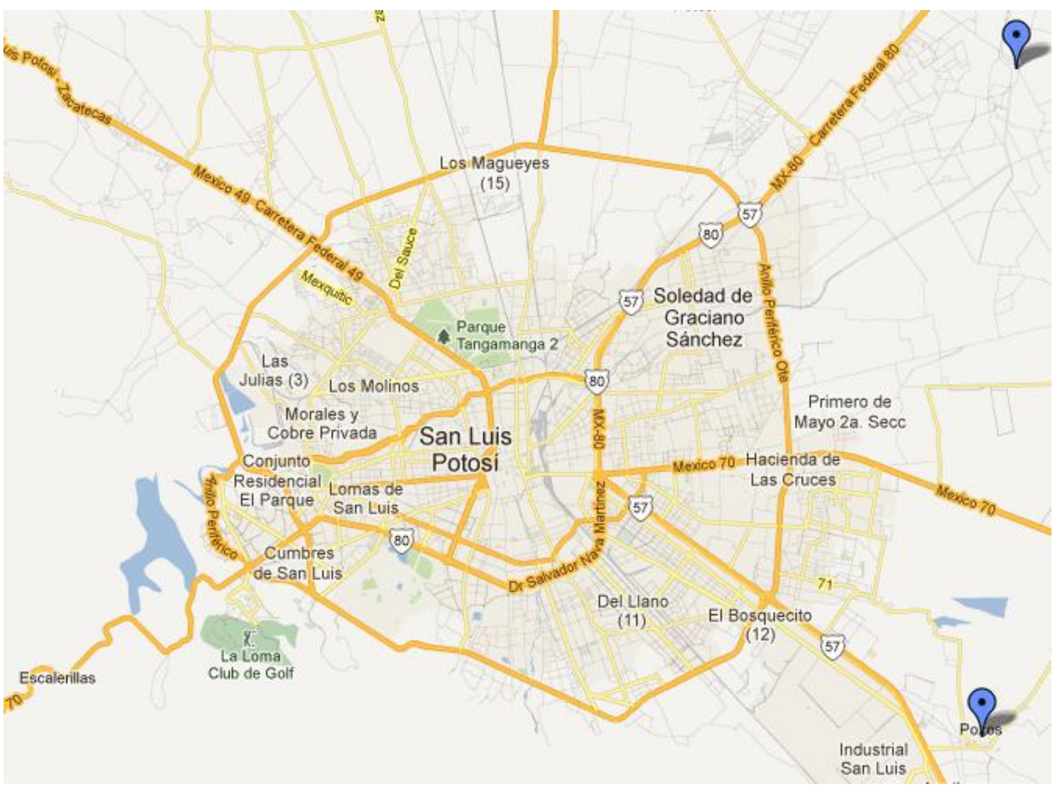

Figure 2 Map of the municipalities of San Luis Potosi and Soledad de Graciano Sanchez

The agricultural activities like livestock production are held mainly in the municipality of Soledad de Graciano Sanchez and in the delegation of Pozos, indicated in Figure 2. While located in the periphery of the city, these settlements are not properly rural because of their proximity to densely populated urban areas.

2.1 Situation of bovine milk production

The State of San Luis Potosi contributes with 6.9 thousand million pesos to the agricultural gross domestic product of Mexico, which represents 2.2% of the national total. In the livestock sector, bovine milk production ranks third in economic importance, with 1.2% of the national production, being San Luis Potosi and Soledad de Graciano Sanchez among the three municipalities with the largest proportion of livestock production in the State (Servicio de Información Agroalimentaria y Pesquera, 2011). Talking specifically of milk production, in 2009 San Luis Potosi and Soledad de Graciano Sanchez were among the six largest producers, as shown in Figure 3.

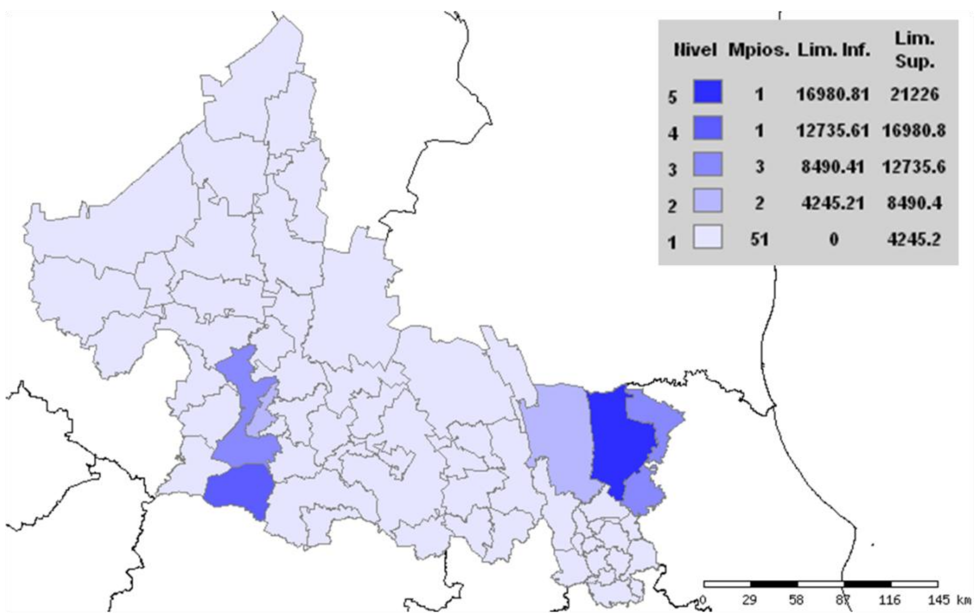

Figure 3 Volume of bovine milk production in thousands of liters (2009)

About the total number of production units and dairy cattle heads, the last agricultural census, executed in 2007, in the State of San Luis Potosi exist 4,431 dairy production units with a total of 49,630 heads, of which the municipalities of San Luis Potosi and Soledad de Graciano Sánchez together account with about 12% of the production units and 10.5% of the heads. Furthermore, in both municipalities around 86% of the production units are backyard or small scale units with a number of heads between 1 and 21 and only about 1% has more than 100 cows. The detailed numbers by municipality are shown in Table 1.

Table 1 Number of dairy production units and heads by municipality

Municipality	No. of production units	No. of heads
San Luis Potosi	251	2127
Soledad de Graciano Sánchez	280	3114

Taking into account the national totals and compared to States like Jalisco or Coahuila, San Luis Potosi is not very significant in terms of dairy production and little attention is paid to manure management or sustainability programs. However, the municipalities of San Luis Potosi and Soledad de Graciano Sánchez are relevant in the State`s context, being both among the largest livestock producers and highest urbanized areas at the same time.

According to the statements of the president of the National Association of Dairy Producers (ANGLAC, for its acronym in Spanish), the Mexican dairy sector is in danger, due to problems with decapitalization and many producers running out of business. The problem is in the global dairy market, as many countries have a support program for the surplus of milk production; those developed countries take the production surplus out of the national market and import it with prices below the production costs, making very difficult to the Mexican farmers to be competitive (Hernández, 2010). Looking only at the San Luis Potosi numbers shown in Figure 4, in the past 10 years milk production has decreased 28.7 percent.

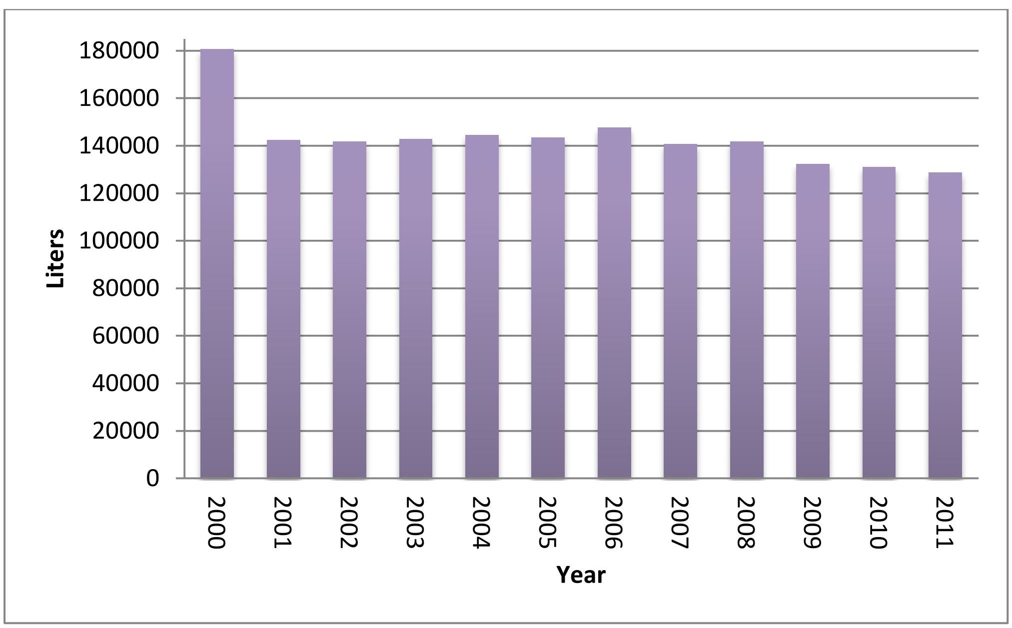

Figure 4 Annual bovine milk production 2000-2011 (thousands of liters)

The different problems that the dairy sector is facing in Mexico highlight the importance of taking relevant measures to improve the market. The government cannot afford to grant the producers with subsidies as other countries do. Therefore, the best way of improving the national producer`s competitiveness is to reduce the production costs, with measures such as improving the energy efficiency of the production process, taking advantage of all the available resources and minimizing the wastes.

3 Objective

To evaluate the current manure management practices in the existing dairy cattle farms in the suburbs of San Luis Potosi City and determine the feasibility of the installation of a biogas digester for manure treatment and as an energy source.

4 Literature Review

4.1 Manure managment

A manure-management system is composed by several steps that may include collection, transfer, storage, treatment, hauling, and disposal or use as fertilizer. For each step, several technologies and different options exist, depending on manure characteristics and final purposes.

For the accounting of green house gases (GHG) emitted by animal feeding operations, the Intergovernmental Panel of Climate Change identified 12 main manure management systems described in Table 2.

In general, the implemented manure management system is related to the size of the farm. Intensive units with large number of heads (more than 300) usually treat and store their wastes as liquid, which are flush or scrape slurry systems.

Anaerobic lagoons are a common option for slurry and liquid manure; this system has several disadvantages, as a lot of water is required for handling and the size is larger than facilities designed for storage only (Ohio State University, 2006). Nonetheless, anaerobic lagoons give biological treatment to manure, reducing odors for further application in the soil, and produces biogas, a mixture of methane and carbon dioxide that can be collected and burned as a fuel.

Table 2 Manure management systems

System	Definition
Pasture/Range/ Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Daily spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Solid storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
Liquid/Slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Uncovered anaerobic lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon. Anaerobic lagoons are designed with varying lengths of storage (up to a year or greater), depending on the climate region, the volatile solids loading rate, and other operational factors. The water from the lagoon may be recycled as flush water or used to irrigate and fertilize fields.
Pit storage below animal confinements	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
Anaerobic digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilization by the microbial reduction of complex organic compounds to CO2 and CH4, which is captured and flared or used as a fuel.
Burned for fuel	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Cattle deep bedding	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for as long as 6 to 12 months. This manure management system also is known as a bedded pack manure management system and may be combined with a dry lot or pasture.
Composting • In-vessel • Static pile • Intensive windrow	The organic matter contained in manure is decomposed by aerobic bacteria; in large-scale farms, industrial composting systems are implemented, using techniques such as mechanical mixing and forced aeration.
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration.

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 10: Emissions from Livestock and Manure Management, Table 10.18: Definitions of Manure Management Systems, p. 10.49.

4.2 Environmental impacts of manure

Manure can cause a negative environmental impact when not properly managed. The high amounts of nutrients that make of manure a good fertilizer, can also pollute soils and water bodies when applied in high amounts. Nitrogen and phosphorus compounds contained in manure are transported to water bodies through surface runoff and infiltration to ground water; an overload of nutrients in water produces eutrophication, a process in which oxygen is depleted from the water body, eventually destroying biodiversity.

In the process of manure decaying, several gases are emitted by the microorganisms that decompose manure. Gas emissions from manure include methane (CH_4), hydrogen sulfide (H_2S), volatile organic compounds (VOC) and nitrogen compounds such as ammonia (NH_3), nitrous and nitric oxide (N_2O, NO), being most of them green house gases. The main factor that determines the amount produced of each gas is how the manure is managed, because some types of storage and treatment systems promote an oxygen-depleted (anaerobic) environment (BANR & BEST, 2003). The most substantial methane emissions from manure management are associated with confined animal management operations where manure is handled in liquid-based systems (IPCC, 2006). Of all the gases mentioned before, methane raises the most environmental concerns for both its emission rates and physicochemical characteristics. Methane is a greenhouse gas 23 times stronger than carbon dioxide (CO_2) and stays an average of 8.4 years in the atmosphere, enough time to be distributed globally (BANR & BEST, 2003).

4.2.1 GHG emissions from manure in Mexico

The Fourth National Communication for the United Nations Framework Convention on Climate Change (UNFCCC) was emitted by Mexico in 2009; this communication shows information regarding the national GHG emissions by sector in the period from 1990 (base line) to 2006. In 2006, the total emissions of the agricultural sector were 45,552.1 Gg of CO_2 eq (SEMARNAT, 2009). The agricultural sector is divided in the following sub-categories:

- Enteric fermentation
- Manure management
- Rice crops
- Crop lands
- Soil burning
- In situ burning of agricultural waste

Particularly of the livestock sector, enteric fermentation and manure management account as the main categories for their important methane emissions. Figure 5 shows the contribution of manure management to the national CH_4 emissions, that is 1,168.8 Gg of CO_2 eq (SEMARNAT, 2009).

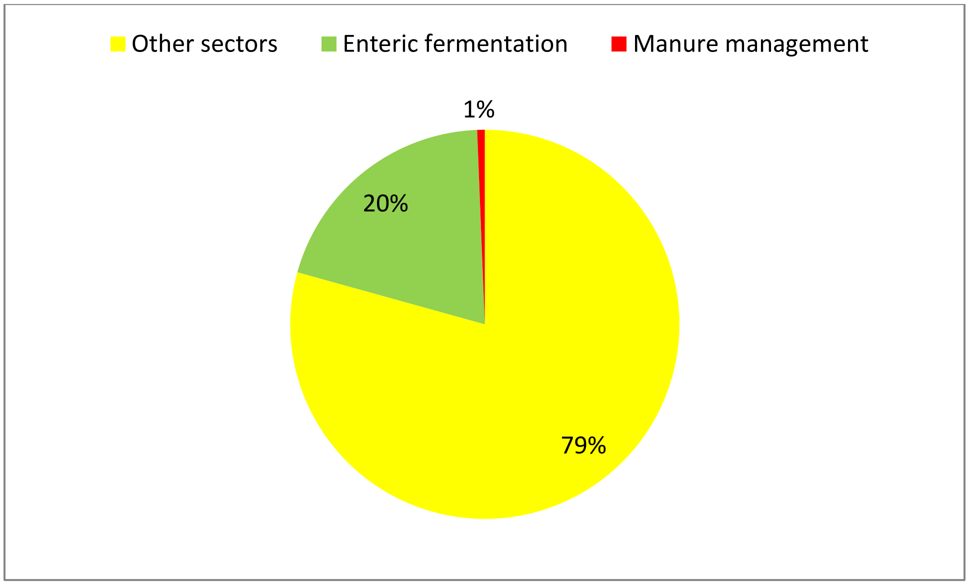

Figure 5 Contribution of the livestock sector to the national CH_4 emissions (2006)

On the period analyzed by the Communication, the volume of the methane emissions has not shown a decrease tendency; as shown in Figure 6, the emissions have remained between the ranges of 1130-1175 Gg CO_2 eq (SEMARNAT, 2009). While there have been reductions in 1992, 1996 and 2000, on the recent years the tendency is more to increase, thus not making the mitigation strategies evident.

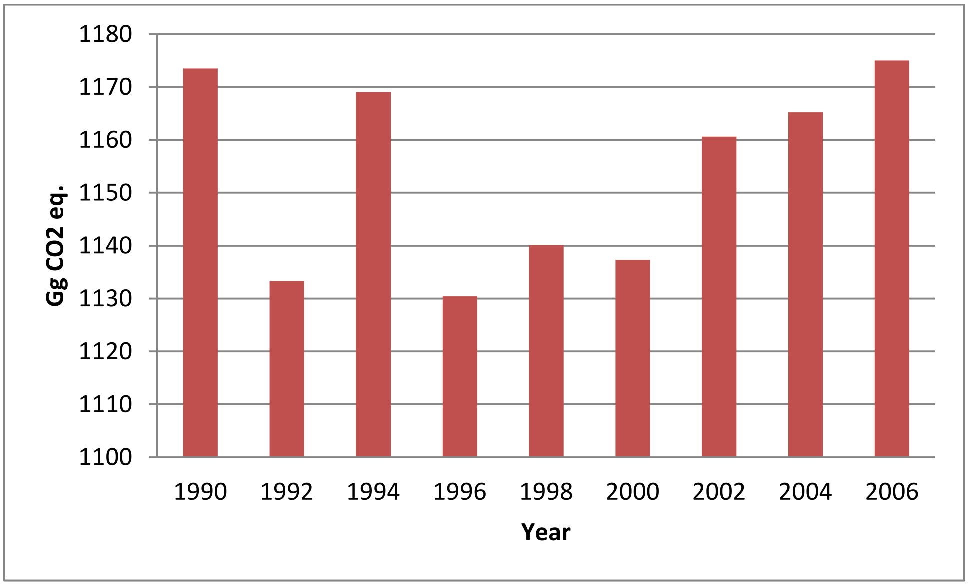

Figure 6 GHG emissions from manure management in Mexico 1990-2006

4.3 Laws and regulations concerning manure management in Mexico

The Ministry of Agriculture (SAGARPA) created a manual of good practices for application in dairy production units; among different guidelines, the manual briefly mentions a program for waste control, with the main objective of improving animal health and milk quality, while complying with the current regulations in terms of waste water discharge.

Manure as such, is not mentioned in any environmental law in Mexico. The Law for Prevention and Integral Management of Waste classifies, in its 19th article, section III, all agriculture and livestock wastes as “special management wastes”. The same law defines this kind of wastes, as those generated in the productive processes but can be considered neither as hazardous nor as municipal solid waste. The law also establishes that it is a competence of each federal state and/or municipality, to determine which wastes are going to be considered for a special management plan.

A waste management plan requires a considerable investment for planning and monitoring by the public authorities; that is why this kind of plans are only implemented for those wastes produced in such quantities, that could represent a problem for its disposal or an environmental risk. Therefore, manure management plans are only considered in those municipalities and/or federal states that have a high livestock density, thus producing large quantities of manure. This is the case of the state of Michoacan, which in its livestock law has included an article that establishes manure management programs as mandatory in those communities with high livestock population density, even though this state does not account as one of the largest livestock producers of the country.

4.4 Biogas

The first identified use of biogas for an energy system was in 1895 in Exeter, England, where gas generated in a septic tank was used for street lighting. In 1920 devices were designed and its use spread all over England, and in countries like Germany and France during World War II when energy supplies where reduced and gas was produced to run vehicles (National Academy of Sciences, 1977). Nowadays, biogas production systems have evolved, and are used mainly as a source of energy for rural areas. According to the 2010 REN21 report, more than 30 million households get lighting and cooking from biogas made in household-scale digesters. Some industries and mainly agricultural units obtain heat and motive power from small scale biogas digesters. Biogas uses for transportation seem to be restricted to local and regional pilot cases (UNEP, 2009)

Biogas is a mixture of gases, product of anaerobic digestion of organic matter. The composition of biogas varies widely according to the substrate and the reactions conditions, such as temperature, pH and humidity. Typical composition of biogas is shown in Table 1; when using manure as a substrate, its physical, chemical, and biological characteristics are related to the animal´s breed and diet quality, which can influence the biogas composition (Balat, 2009).

Table 3 Biogas composition

Substance	% by volume
Methane	55-65
Carbon dioxide	35-45
Hydrogen sulphide	0-1
Nitrogen	0-3
Hydrogen	0-1
Oxygen	0-2
Ammonia	0-1

Anaerobic digestion of organic matter consists of a complex series of reactions where a mixture of microorganisms is involved. Although methane generation is widely extended, the direct precursors of methanogenesis are just a few. Organic polymers like starch, cellulose, hemicellulose and pectin are hydrolysed to shorter molecules like glucose and cellobiose. Monomers are then metabolized by fermentative bacteria transforming them into hydrogen (H_2), carbon dioxide (CO_2) and Volatile Fatty Acids (VFA), mainly acetate, butirate and propionate. Secondary fermentation or acetogenesis, generates H_2, CO_2 and acetate. Finally, from these 3 products, methanogenic organisms produce methane (Smith, 1992; Carrillo, 2003).

Substrates for biogas productions can be many and from very diverse origins. The most common are wastewaters, sludge from sewage and treatment plants, municipal solid waste (landfills) and agricultural wastes like crop silage and animal manure (Balat, 2009). The selection of a feedstock for biogas production has to consider methane yield as the most important economic parameter (Smith, 1992). That's why crops for feeding purposes are being used for energy production instead, as they have high biogas yields. When using energy crops, ecological and land use impacts must be considered, while organic wastes do not require extra land and are thought to have particularly good potential as a renewable energy source that reduces ten times more GHG than crops[1] (UNEP, 2009).

The microbial processes which naturally take place during metabolizing of manure components can be used in a controlled conversion in a technical process to produce biogas. Many advantages result from this: climate related emissions of CH_4 are partly or fully prevented. The quality of the manure and its applicability as a fertilizer are improved.

[1] 5.5 vs.0.5 kilos of CO2 equivalent per cubic meter of methane produced.

Easily degradable odor producing substances and aggressive organics are metabolized and therefore no longer emitted in large amounts. Thus air pollution is reduced and the fertilizing effect is improved. It is an even more important benefit that biogas is a renewable energy source which can replace fossil fuels for the generation of electrical power and heat since it causes extra climate benefits by avoidance of fossil fuel burning GHG emissions (Soyez & Grassl, 2008).

Dairy cattle manure can produce up to 45 cubic meters of biogas per ton when handled as a solid, with average 60% methane content; this value is low when compared to pig manure and poultry feces (FNR). Lower yields from cattle manure are because energy rich substances are used during rumen digestion (Soyez & Grassl, 2008); however, a cow produces far more manure per day than a pig or a chicken, compensating the lower biogas yields with higher feedstock availability (See Table 4).

Table 4 Manure production per animal and biogas yield

<table>
<tr><th>Animal</th><th>Manure production (kg/day)</th><th>Biogas potential yield (m^3)</th><th>CH_4 content (%)</th></tr>
<tr><td>Poultry, layer</td><td>0.12</td><td rowspan="2">80</td><td rowspan="2">60</td></tr>
<tr><td>Poultry, broilers</td><td>0.08</td></tr>
<tr><td>Swine</td><td>4.5</td><td>60</td><td>60</td></tr>
<tr><td>Cattle, beef</td><td>36</td><td rowspan="2">45</td><td rowspan="2">60</td></tr>
<tr><td>Cattle, dairy</td><td>54</td></tr>
</table>

Sources: Ohio State University (2006) and Fachagentur Nachwachsende Rohstoffe

Manure production is a function of many factors: diet quality and quantity; animal age, size and breed. Nevertheless, the data shown in Table 4 are average values, and give a general idea of the volume of manure that can be obtained of each livestock. Taking into account this data, 4 dairy units could satisfy the energy needs of one household (Soyez & Grassl, 2008).

Temperature is another important factor to consider as biodigesters work better in warm weather, but still under these conditions several months are required to fully stabilize manure (Ohio State University, 2006). There are different kinds of methanogenic bacteria that require different temperatures to achieve its optimum biogas production yield. Some populations have a better performance at temperatures in the range of 70˚C; this would require external heating, which would make the biogas system more elaborated and thus, more expensive. Some other bacteria work better in the range of 30 to 35˚C, temperatures that can be achieved in tropical climates. With temperatures below the optimum range, methanogenic bacteria still work but at a slower pace, which would extend the retention time needed to obtain the maximum biogas yield. Table 5 shows the retention time in days as a function of temperature (Martí Herrero, 2008).

Table 5 Retention time as a function of temperature

Temperature (˚C)	Retention time (days)
30	20
20	30
10	60

Another important factor for the good functioning of a biogas system is the water content. Manure needs to be mixed with a good amount of water in order to allow the continuous flow of the manure in and out of the digester; furthermore, water helps to dissolve the volatile organic solids present in manure, making them more available for the bacteria. Based on experimental experience, a ratio of 1 portion of bovine manure with 3 portions of water gives a good performance to the biodigesters (Martí Herrero, 2008).

4.5 Biodigesters types

Biogas digesters are anaerobic reactors that vary widely on size and design. Simple one stage digesters with an extraction hood are the most common in rural areas; the bag-type digester is very useful in tropical and subtropical regions (Carrillo, 2003). More efficient systems, where more maintenance and operation control is required like granular sludge-based bioreactors, such as the upflow anaerobic sludge blanket (UASB), expanded granular sludge bed and the anaerobic hybrid reactor (Balat, 2009) are used mainly in developed countries.

In the case of Mexico, while some high-tech biogas plants have been installed, most of the dairy producers are small scale, which makes these kinds of technologies economically unfeasible. For that reason, small-scale low-cost biodigesters are the best option for the majority of the Mexican dairy production units. Three main designs have been identified as the most widely used models in developing countries: floating dome, fixed dome and plastic foil biogas plants.

4.5.1 Floating dome

The floating dome biogas plant is used mainly in India. This model allows keeping a constant gas pressure, making also possible to meter the gas volume. In the other hand, the floating dome is corrodible due to steel construction and leads to high construction costs.

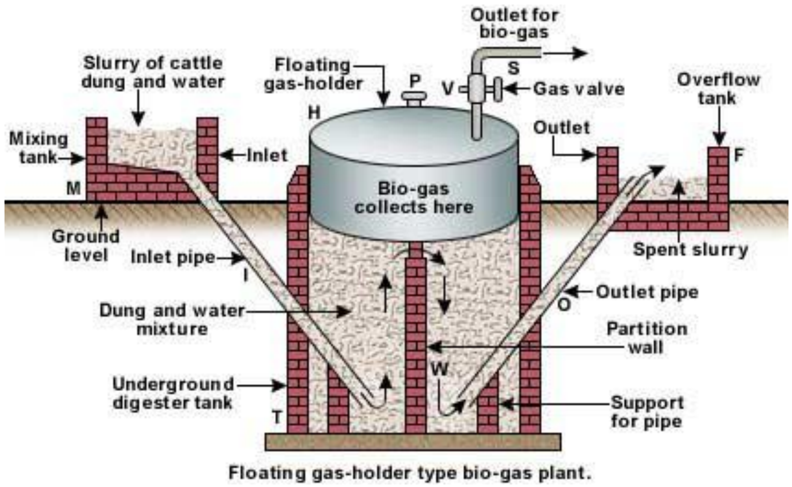

Figure 7 Floating dome type biogas plant.

4.5.2 Fixed dome

The fixed dome biodigester is predominant in China. As well as the floating dome type, it is constructed underground, which does not allow high temperature deviations. Another advantage of this model is the long life time, and being a single unit it has no moving parts that require high maintenance. In the fixed dome biogas plants, the pressure is not constant and gas leakages to the atmosphere are possible.

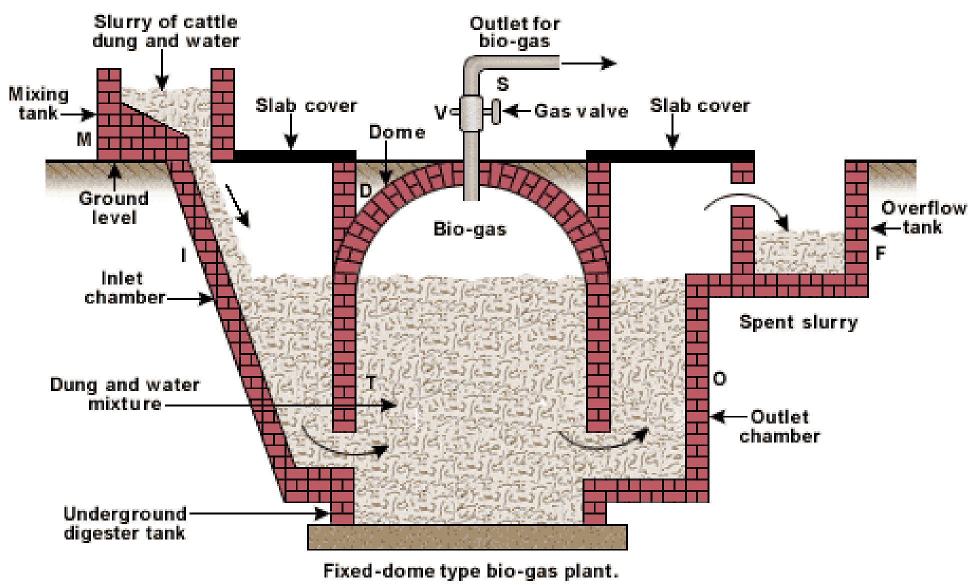

Figure 8 Fixed- dome type biogas plant.

4.5.3 Plastic foil (bag-type)

Plastic foil biodigesters are the main technology that has been implemented in Latin America. In Bolivia, for example, the German Society for International Cooperation (GIZ, former GTZ, for its acronym in German) has promoted the dissemination an implementation of plastic foil biogas plants throughout the country; this model is based in tubular polyethylene for its construction. Polyethylene, while having acceptable resistance to solar irradiation, can be easily punctured and its life time period is not very long (5 years maximum).

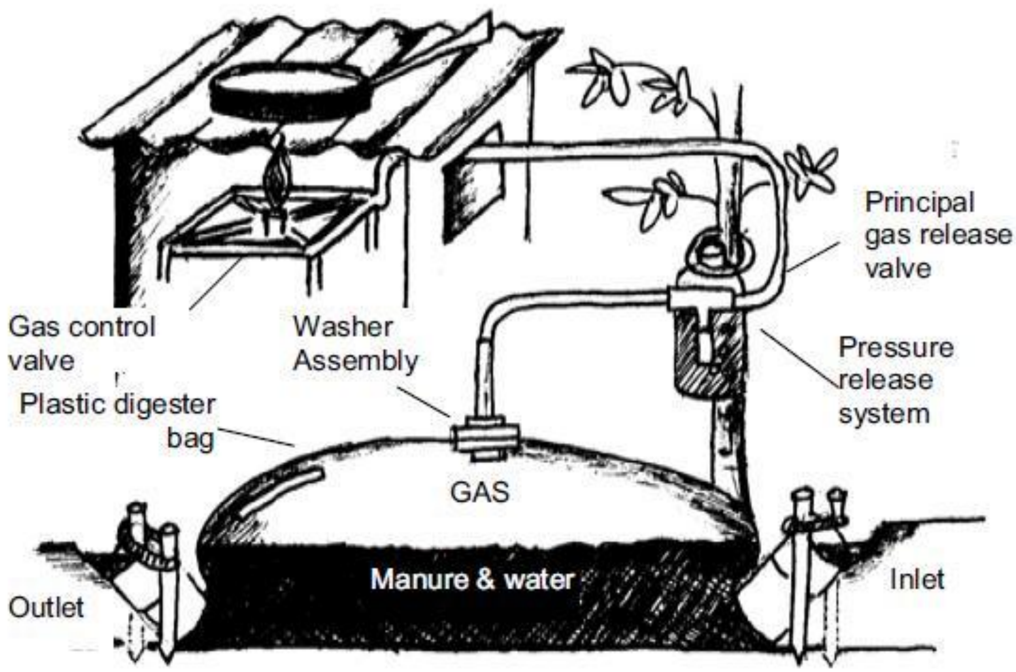

Figure 9 Bag-type biogas plant

The main advantages of bag-type systems are its flexibility and mobility. Those systems that require civil works imply highest construction and installation costs, which guarantee a higher life period, but makes impossible to move the installation. Bag-type systems constructed with geomembrane instead of polyethylene can last up to 25 years.

5 Methodology

Different methodologies were applied for different stages of the project. An extensive literature review was necessary through all stages to have a framework on which to support the research.

The environmental benefits of treating manure anaerobically have been presented as part of the literature review and the biogas production potential is going to be calculated using a mathematical model. An economic analysis is also relevant in order to justify the sustainability of such a project. In case that the economical benefits exceed the investment costs, this would be reflected in the life quality of those producers installing a biodigester, thus having a positive social impact as well.

5.1 Interviews and field visits

In order to collect statistical information of the dairy sector in the municipalities of San Luis Potosi and Soledad de Graciano Sánchez, interviews were conducted in several institutions related to the sector that may have information already collected from the farmers, like manure management practices and records of biodigesters already installed. The institutions interviewed were the following:

- SAGARPA, Ministry of Agriculture
- SEDARH, Agriculture secretary for the State of San Luis Potosi
- FIRCO, Institution that provides financing to agro-business
- INEGI, National institute of statistics and geography
- The regional union of livestock producers
- Health committee for livestock protection
- IRRI, International Institute of Renewable Resources

In order to hear the personal experiences of the region´s dairy producers, field visits took place in two representative communities: Palma de la Cruz in Soledad de Graciano Sánchez and Villa de Pozos in San Luis Potosi (see Figure 2). Structured interviews were conducted to small and medium size farms. The questions asked were divided in 4 main topics:

I. General data about the livestock
II. Manure management practices
III. Energy uses
IV. Water uses
V. Socio-economic information
VI. Previous knowledge of biogas systems

The answers given by the producers and the inspection of the farms provided the information required to determine the most common manure management practices on the area and to make the analysis for the potential of a biogas system.

Besides the interviews, a field visit was made to the installation of a bag-type biodigester as well as to small-scale dairy farms that have a functioning biogas system with their owners already making us e of the biogas produced.

5.2 Mathematical model

Climate Action Reserve, a program that works to establish regulatory quality standards for the development, quantification and verification of greenhouse gas (GHG) emissions reduction projects in North America, has developed a series of equations that allows to calculate the baseline emissions according to the manure management system in place prior to installing the biogas system, thus estimating the biogas production potential and the reductions of GHG emissions. The model is designed for medium and large scale animal feeding operations (AFOs) containing cattle and/or swine.

The model is based in the Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines for National Green House Gases Inventories and in the work of Mangiano *et al*, which developed a procedure to determine a country-specific methane conversion factor (MCF) for anaerobic lagoons by taking into account the effect of temperature in biological activity, using the van´t Hoff-Arrhenius equation. Climate Action Reserve also provides the standard data tables to calculate emissions from manure management specifically for the Mexican case, with data from research carried out by González-Ávalos with cattle manure from Mexico.

The model consists of a group of equations based in different parameters; some of them are site-specific, others can be obtained from tables, and others are constant. The model also offers the possibility to calculate the base-line emissions for anaerobic and non-anaerobic management systems.

Table 6 Parameters required for calculations of methane emission potential

Parameter		
Site-specific	**Tables**	**Constant**
Population	Volatile solids*	Activation energy constant
Animal weight	Maximum methane producing capacity *	System calibration factor
Temperature	Methane conversion factor for manure management system	Ideal gas factor
Portion of manure* managed in non-anaerobic system		

*By livestock category

5.2.1 Modeled equations to calculate the methane production potential of anaerobic treatment systems

For this analysis, the equations for anaerobic systems will be used to estimate the biogas production potential in terms of the estimated methane emissions in case that all the manure produced in the visited farms was given an anaerobic treatment, namely, in a biodigester for biogas production.

Equation 1 Methane emissions from anaerobic storage/treatment systems

$$BE_{CH4,AS} = \sum_{L,AS} VS_{deg,AS,L} \cdot \ B_{0,L}$$

Where,

$BE_{CH_4,AS}$ = monthly methane emissions from anaerobic manure storage/treatment systems

$VS_{deg,AS,L}$ = annual volatile solids degraded in anaerobic manure storage/treatment system 'AS' from livestock category 'L' (kg dry matter)

$B_{0,L}$ = maximum methane producing capacity of manure for livestock category 'L' (m3 CH4/kg of VS) – (Appendix B)

Equation 2 volatile solids degraded by anaerobic manure storage/ treatment system

$$VS_{deg,AS,L} = \sum_{AS,L} VS_{avil,AS,L} \cdot f$$

Where,

$VS_{deg,AS,L}$ = monthly volatile solids degraded by anaerobic manure storage/ treatment system 'AS' by livestock category 'L' (kg dry matter)

$VS_{avail,AS,L}$ = monthly volatile solids available for degradation from anaerobic manure storage/treatment system 'AS' by livestock category 'L'(kg dry matter)

f = the van't Hoff-Arrhenius factor, that according to Mangiano *et al* is: "the proportion of volatile solids that are biologically available for conversion to methane based on the monthly temperature of the system"

Equation 3 Volatile solids available for degradation in anaerobic storage/treatment system

$$VS_{avil,AS,L} = \left(VS_L \cdot P_L \cdot MS_{AS,L} \cdot dpm \cdot 0.8\right)$$

Where,

$VS_{avail,AS,L}$ = monthly volatile solids available for degradation in anaerobic storage/treatment system ‘AS’ by livestock category ‘L’(kg dry matter)

VS_L = volatile solids produced by livestock category ‘L’ on a dry matter basis (kg/animal/day) (Appendix B)

P_L = annual average population of livestock category ‘L’ (based on monthly population data)

$MS_{AS,L}$ = percent of manure sent to (managed in) anaerobic manure storage/treatment system ‘AS’ from livestock category ‘L’ (%)

dpm = days per month

0.8 = system calibration factor

Equation 4 The van’t Hoff-Arrhenius factor

$$f = exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right]$$

Where,

f = the van’t Hoff-Arrhenius factor

E = activation energy constant (15,175 cal/mol)

T_1 = 303.16K

T_2 = monthly average ambient temperature (K). If $T_2 < 5$ °C then $f = 0.104$; if $T_2 > 29.5$ then $f = 0.95$

R = ideal gas constant (1.987 cal/Kmol)

Equation 5 Daily volatile solids for all livestock categories[2]

$$VS_L = VS_{table} \cdot \left(\frac{Mass_L}{TAM_L}\right)$$

[2] According to the Clean Development Mechanism (CDM) methodology, the VS_L value from tables should be adjusted to site-specific animal-mass data.

Where,

VS_L = volatile solid excretion on a dry matter weight basis (kg/animal/day)

VS_{Table} = volatile solid excretion from lookup table (Appendix B) (kg/animal/day)

$Mass_L$ = average animal mass for livestock category 'L' (kg), if site specific data is unavailable, use MTP_L

TAM_L = typical average mass (kg) from lookup table (Appendix B)

5.2.2 Modeled methane emission equations for non-anaerobic management systems

The following equations will be used to calculate the methane emissions that occur when the manure is handled with any of the following techniques:

- Pasture/Range/Paddock
- Daily spread
- Solid storage
- Dry lot
- Liquid/Slurry
- Pit storage below animal confinements
- Burned for fuel
- Deep bedding
- Composting

Equation 6 Total annual methane emissions from non-anaerobic management systems

$$BE_{CH4,nAS} = \left(\sum_{L,S} P_L \cdot MS_{L,n,AS} \cdot VS_L \cdot MCF_{n,AS} \cdot B_{0,L} \cdot 365\right) \cdot (0.717 \cdot 0.001 \cdot 21)*$$

Where,

$BE_{CH4,nAS}$ = total annual baseline methane emissions from non-anaerobic storage/treatment systems

P_L = annual average population of livestock category 'L' (based on monthly population data

$MS_{L,nAS}$ = percent of manure from livestock category 'L' managed in non-anaerobic storage/treatment systems (%)

VS_L = volatile solids produced by livestock category 'L' on a dry matter basis (kg/animal/day) – Important - refer to Box 2 for guidance on using appropriate units for VSL values from Appendix B.

$MCF_{n,AS}$ = methane conversion factor for non-anaerobic storage/treatment system 'S' (%) – (Appendix B)

$B_{0,L}$ = maximum methane producing capacity for manure for livestock category 'L'

365 = days in a year

* The second part of the equation is used when the total annual emissions are reported as tons of carbon dioxide equivalents (tCO_2e/yr).

Where,

0.717 = methane density conversion factor, m^3 to kg (at 0°C and 1 atm pressure)

0.001 = conversion factor from kg to metric tons

21 = Global Warming Potential factor of methane to carbon dioxide equivalent

Equation 5 is also used for aerobic systems to adjust the volatile solids excretion, given that the animal mass data is available.

5.3 Economic feasibility analysis

Before every investment project, it is important to assess its feasibility considering both advantages and disadvantages; an economic analysis provides important information for the decision-making process. It is important to consider that the value of money changes with time, i.e., due to inflation, taxes, and other factors, money incomes in the future normally will have less value as if the same quantity was received in the present. There are three different methods to assess an individual project by comparing the changing value of money across time:

- Annual equivalent rate (AER)
- Net present value (NPV)
- Internal rate of return (IRR)

These methods are equivalent, i.e., if the same investment project is analyzed with each one of them, the three methods will give the same answer in terms of a decision: the investment should or should not be done (Coss Bu, 2005). The net present value has de advantage of being unique, independently of the behavior that the cash flows generated by the investment project follow; this characteristic makes the NPV preferable for those situations where the irregular behavior of the cash flows generates several return rates (Coss Bu, 2005).

5.3.1 Net present value (NPV)

The net present value is one of the most used economic criteria for the assessment of investment projects. The NPV determines, at the time "cero", the equivalence of the future cash flows that a project generates and compares this equivalence with the initial expenditure; when that equivalence is higher than the initial investment, then, it is advised to accept the project (Coss Bu, 2005).

The following equations in used to determine the present value of the cash flows generated by an investment project:

Equation 7 Net present value

$$NPV = S_0 + \sum_{t=1}^{n} \frac{S_t}{(1+i)^t}$$

Where,

NPV= Net present value

S_0 = Initial investment

St = Net cash flow for the period t

n = number of life periods of the project

i = minimum acceptable rate of return (MARR)

The value of MARR can be easily established taking into account several factors such as the risk that represents certain project, the money availability and the prevailing inflation rate in national economy (Coss Bu, 2005); when this information is not available, the MARR can be set as a percentage that represents the minimum profit margin that is expected to obtain from an investment project.

For the investment project, it is necessary to consider the initial costs with the cash flows. The initial costs would include the equipment and installation costs, while the net cash flow would include the incomes and the regular expenses.

By installing a biogas system to produce biogas for own use, either by direct combustion or power generation, instead of having an actual profit, the incomes will come as savings from either the gas or the electricity bills. In order to illustrate this better, Table 3 shows which parameters should be considered for this evaluation.

Table 7 Investment costs and cash flows of a biogas system project

Investment costs	**Cash flows**	
	Savings (Incomes)	Expenses
Equipment	Electricity/Gas bills	Operation costs
Installation	Fertilizer	Maintenance

6 Results and Discussion

6.1 Interviews with institutions

After carrying out an exhaustive research on internet and printed sources, it was found that the current information available in terms of manure management practices and biodigesters installed on dairy farms in Mexico is very scarce. Regarding manure management practices, the INEGI does not keep statistics and neither SAGARPA nor SEDARH have any program. In terms of regulations of manure management and disposal, the chief of the Ecology Depatment of the municipality of San Luis Potosi expressed that there is no control in this respect, unless high concentrations of manure in densely populated areas could represent a health threat.

About biodigesters, there is no compiled information of how many, what kind and where have been installed biogas systems in the country. The only information available is the one provided by the “Bioeconomy program” financed by FIRCO, which promotes the use of renewable energy sources on the agricultural sector, including biogas. This program was first approved in 2008 as a pilot project, the “Proyecto de Apoyo para la Generación y Aprovechamiento de Biogas en Explotaciones Ganaderas” (project of support for biogas generation and use in livestock production units) under the “Fondo para la Transición Energètica y el Aprovechamiento Sustentable de la Energìa” (Fund for the energy transition and the sustainable use of energy) to provide livestock producers with economic resources to install a biogas digester. This project was focused on electricity generation with the main objective of methane emissions reduction. There were 3 areas on which a livestock producer could apply to obtain the financial support: (SAGARPA, 2008)

1. To install an electricity generator for a already existing biogas digester;
2. To install a complete system of digester and generator to supply the farm with its electricity needs in order to reduce operation costs, and
3. For intensive livestock operations; the objective was the installation of a biogas system integrated to the CDM, generating electricity to reduce costs and participate in the carbon- bonds market.

The requirement to be eligible for this project was to have at least 300 cows in a dairy farm. This point ruled out all small operations and familiar units; poor producers were not the target of this project and therefore could not aim to receive support from this initiative. In 2010, the biogas project for farms was re-launched under the “Bioeconomy proyect”, among other renewable energy sources. This time, the project opens the possibility to small scale production units to apply for the fund´s support; nonetheless, in order to provide the support of the fund, the following prioritization criteria are applied:

a) To be located in a region where the amount of organic waste causes pollution problems to water bodies and regional soils;
b) The project is part of a group of projects concentrated on a regional level;
c) Confined livestock facilities with more than 300 heads and electricity consumption higher than 1000kWh per month;
d) For production units smaller than the ones indicated on the previous point, it could be possible to install a biogas system with demonstrative purposes (max. 3 per municipality) in order to promote the technology in those areas with high livestock population, given that the project is economically feasible;
e) The production unit must have a proper system to collect manure;
f) The production unit already has an anaerobic lagoon.

Small-scale farms can be granted with 50% of the installation costs, given that this does not exceed $500,000 MXN; furthermore, an additional support of $500,000 MXN or 50% of the total cost of a generator to produce electricity with biogas can also be obtained (FIRCO, 2012).

6.2 Biogas systems in Mexico

There is no census or statistic record regarding the number of biogas systems already installed and functioning in Mexico; the only information available is the one from the Bieconomy Project. FIRCO keeps a record of the number of projects that received the support of the fund since 2008 and updated only till 2010 (See Table 8). Until 2010, 237 biogas systems have installed in Mexico with support of the Fund (FIRCO) .

The region known as “Comarca Lagunera”, located in the States of Coahuila and Durango, has installed the highest number of biodigesters with a total of 63, followed by Jalisco with 33 biogas systems. The State of Jalisco and the “Comarca Lagunera” are the regions with the highest population of dairy cattle and largest production units in Mexico (FIRCO).

In San Luis Potosi, there has been installed only one biodigester with the support of the fund. According to the information provided by the person in charge of the project in the offices of FIRCO in San Luis Potosi, the biogas system was installed in a ranch located in Villa de Reyes, a municipality adjacent to San Luis Potosi. The main activity of the production unit is dairy products with a total population of 1800 heads, but also has an adjacent swine farm. The ranch received $1,000,000 MXN for the installation of the biodigester and also a 60 kW generator. However, the generator is not in use currently as the biogas is used to replace diesel for the boilers, which represents savings of $140,000 MXN annually (Ascencio, 2012).

Table 8 Number of biodigesters and generators installed in Mexico by State with the support of the Fund for the energy transition and the sustainable use of energy in the period of 2008-2010

State	2008		2009		2010	
	Biodigester	Generator	Biodigester	Generator	Biodigester	Generator
Aguascalientes	0	0	7	2	8	8
Baja California Norte	0	0	0	0	0	1
Baja California Sur	0	0	0	0	1	1
Campeche	0	0	4	0	1	4
Chihuahua	1	0	0	0	3	0
Colima	1	0	2	0	0	3
Edo. México	3	0				
Guanajuato	0	0	8	0	14	5
Jalisco	0	0	23	4	10	9
Michoacán	1	0	2	2	0	0
Morelos	0	0	3	0	5	0
Nuevo León	0	0	8	2	7	7
Puebla	2	0	0	0	2	0
Querétaro	0	1	2	0	2	2
San Luis Potosí	0	0	0	0	1	0
Sinaloa	0	2	2	1	0	2
Sonora	0	0	2	0	0	0
Yucatán	37	2	5	0	5	30
Zacatecas	0	0	1	0	0	0
Comarca Lagunera	0	5	41	2	23	12
Total	**45**	**10**	**110**	**13**	**82**	**84**

According to the personnel of FIRCO in San Luis Potosi, there is another project that has requested the support of the Fund and is in evaluation process. The producer that wants to participate in the Bioeconomy Program has to quote the project costs with at least 3 companies to justify the investment by choosing the company that supplies that the best offer. The final decision is made by a national committee which makes a technical evaluation of the project in order to determine its feasibility (Ascencio, 2012).

For a project to be a candidate to receive the support of the Fund, the company that will install the biogas system has to be certified by FIRCO. However, until now FIRCO has not certified any company, so the existing projects have been carried out by companies still in certification process. To this day, there are 14 companies in certification process, 11 that have verified, 17 registered as providers of biogas system and 7 in registration process (FIRCO).

6.3 Interviews with the producers and visits to dairy farms

As a sample of each municipality, one community was selected from San Luis Potosí and one from Soledad de Graciano Sánchez: Villa de Pozos and Palma de la Cruz, respectively. These communities were selected due to their concentration of dairy production units. Seven interviews were carried out : 3 in Villa de Pozos (end of March 2012) and 4 in Soledad de Graciano Sánchez (end of April 2012). More interviews were planned, but the farmers are normally quiet, mistrustful people that because of their low level of education sometimes are victims of fraud and intermediaries taking advantage of them. Added up to this, the resent problems with organized crime that the region is suffering make them feel uncomfortable sharing information about their property and activities; one of the farmers of Palma de la Cruz started to have doubts and to feel suspicious in the middle of the interview, giving incomplete information.

All of the farmers recalled having participated in the last agricultural census of 2007 carried out by the INEGI. Two of the producers of Villa de Pozos stated to be members of the delegation´s livestock producer association. Also, two of the producers of Palma de la Cruz said to be subscribed in the livestock producers association of Soledad de Graciano Sánchez but mentioned that they do not attend the meetings regularly.

6.3.1 General data about the livestock

On the seven visited farms, the number of cows ranged from 12 to 90, with an average of 42 heads per production unit; four of the farms have bulls and the rest use insemination, and the number of calves ranges from 10 to 65, proportionally to the number of cows. The detailed information can be seen in Table 9, where the production units were classified by community and numbered in the order of application. According to the farmers, the average number of heads remains more or less constant over the year and it is similar to the population present at the moment of the interviews.

Table 9 Livestock population of the visited farms

Population	Villa de Pozos San Luis Potosí			Palma de la Cruz Soledad de Graciano Sánchez			
	1	2	3	4	5	6	7
Milking cows	90	37	50	42	30	38	12
Bulls	0	2	0	0	1	2	0
Calves	65	12	25	35	15	16	10

Holstein was the breed of all the dairy cows the visited farms; it is the most common bread due to its adaptability and high milk production yields. A mature milking-cow of this breed normally weights between 500 and 550 kilograms with the proper feeding and milking regime; the interviewed producers said the average weight of their cows to be approximately of 500 kg. All the farmers mentioned to feed their cattle with alfalfa as fodder and concentrate to for energy and protein.

Five of the seven farms have other farm or domestic animals like swine, horses, hens, sheep and dogs, but only in small numbers and always considerably less that the total cattle population; in any case, the manure of all this animals could be incorporated to a biogas system together with the dairy cattle manure.

Table 10 Existence of farm animals other than cattle

Animal/Farm No.	1	2	3	4	5	6	7
Chicken	-	-	-	-	15	-	5
Swine	-	-	-	15	-	10	13
Sheep	-	-	-	-	-	10	-
Horse	-	5	-	2	-	4	-
Dog	-	2	-	2	1	-	-

6.3.2 Manure management practices

In all the visited farms, the manure management system was identified to be dry lot. Seven of the farmers also own crop land but only three of them expressed that part of the manure is applied as fertilizer twice a year. In the other hand, all of the farmers give most of the manure to brick factories that collect it and use it dry to mix it with the clay. Most of the farmers give the manure in return of the cleaning of their pens once or twice a month, but two of the farmers said that they also get paid around 150 pesos for a 4 tons truck of manure. None of the farmers had any specific knowledge about good practices or regulations for manure management.

Figure 10 View of one of the pens located in Palma de la Cruz

Figure 11 Workers from a brick factory collecting manure in a farm located in Palma de la Cruz

6.3.3 Energy uses

In all the visited farms, the production units were connected to the electrical network, being supplied with electricity by the Federal Electricity Commission (CFE, for its acronym in Spanish), which is a public company and the only one providing this service in Mexico. None of the farmers experiences problems with the electricity supply, except for short black-outs that do not involve major problems.

Of the seven visited farms, only one of them was located in the same property were the family lives (No. 5), so only this unit presented domestic uses of energy like gas for cooking and electricity for appliances. On the remaining farms, the energy uses were concentrated in activities related to milk production; the following activities were recognized as the main ones:

- Electricity uses for:
  - Water pumping
  - Lighting
  - Milking machine
  - Refrigerators
- Diesel/Gasoline:
  - Trucks
  - Electricity generator
  - Milking machine

In terms of electricity use, the producers do not know their consumption in energy units (kWh); the idea they have of their energy use is by the amount of money they have to expend on it, so the electricity consumption was recorded as monthly expenditure, in this case according to the CFE billing. In Table 11 the information about electricity uses and approximate cost (billing) according to the farmers is shown.

Table 11 Electricity uses and billing of the dairy farms

Community	No.	Electricity uses	Billing (MXN)
Villa de Pozos	1	Water pumping, Milking machine, Refrigerator, Lighting	4000 monthly
	2	---	---
	3	Milking machine, Lighting	800 monthly
Palma de la Cruz	4	Water pump, Milking machine, Refrigerators, Lighting, Appliances	1000 monthly (special tariff for agriculture) 5000 bimonthly
	5	Water pump, Milking machine, Lighting, Appliances	Without information
	6	Milking machine, Lighting	2000 bimonthly
	7	Milking machine, Lighting	800 monthly (house) 800 monthly (farm)

Even though all of the production units count with good electricity supply, some of the producers own small electricity generators to run the milking machines, as cows have to be milked twice a day, they consider necessary to have a back-up system. The electricity generators run with gasoline. One of the farmers owns a milking machine that runs directly with gasoline instead of electricity. As well as with electricity, the producers do not know their fuels combustion by volume, rather by the costs they imply.

Table 12 Liquid fuels uses and costs in the dairy farms

Community	No.	Gasoline and Diesel uses	Cost (MXN)
Villa de Pozos	1	Trucks, back-up generator	5000 monthly (trucks) 200 monthly (generator)
	2	Trucks, tractor, generator, milking machine	1000 monthly (only for generator and milking machine)
	3	Truck	Without information
Palma de la Cruz	4	Trucks, generator	Without information
	5	Trucks	Without information
	6	Trucks, Tractor, back-up generator	4000 monthly
	7	Trucks	600 monthly

6.3.4 Water uses

Most of the farms use the water for the same purposes: watering the cattle and washing the milking area. The properties that include crop lands depend on the raining season, so they do not need irrigation. Four of the visited farms count with a small well for water supply; the remaining farms use the water from the municipal water supply network. In both cases, none of the farmers said to have experienced shortage problems, even though the region commonly suffers of long periods of drought.

Table 13 Water sources of the dairy farms

Town	Farm No.	Water source
Villa de Pozos	1	Small well
	2	Small well
	3	Tap water
Palma de la Cruz	4	Small well
	5	Small well
	6	Tap water
	7	Tap water

6.3.5 Socio-economic information

In small-scale production units, it is very common that all the family collaborates with the farm work. As shown in Table 14, in five of the visited farms the work is only in charge of the family, mainly the owner, his wife and sons; only two of the producers have employees to help them with the daily labor.

Table 14 Number of people working on each dairy farm

Town	Farm No.	Family members	Employees
Villa de Pozos	1	5	0
	2	5	0
	3	3	0
Palma de la Cruz	4	1	3
	5	1	1
	6	3	0
	7	3	0

Milk production is the central activity of all the visited production units, thus being the main source of income and economic importance for the producers and their families. All of the farmers have a client to whom they sell all of their production. These clients are mostly local cheese producers, No. 1 of Villa de Pozos, who sales the milk to a bigger company (Nestle). The owner of the production unit No. 4 of Palma de la Cruz, has started his own cheese factory.

Five of the seven visited properties also have crop lands, ranging from 2 to 8 hectares of extension (See Table 15). Four of the five producers grow alfalfa to feed their cattle; the remaining farmer only grows corn and beans for own consumption while he buys the necessary alfalfa for the cattle.

Table 15 Crop land extension and main crops grown

Town	Farm No.	Land extension (Ha.)	Crops
Villa de Pozos	1	‘---	---
	2	6	Alfalfa
	3	5	Corn, beans
Palma de la Cruz	4	2	Alfalfa, corn
	5	---	---
	6	8	Alfalfa, corn, oat, sorghum
	7	4	Alfalfa

6.3.6 Previous knowledge of biogas systems

Only three of the interviewed farmers had basic knowledge of biogas systems; two of them said to have heard or seen something on TV. In the other hand, the producer No. 1 of Villa de Pozos expressed that his client (Nestle) told him about it and offered to pay him more for each liter of milk if he installed a biodigester in his farm; he was very interested but said that the installment cost are too high and he could not afford it.

When explained how a biodigester can function with manure and the uses they could give to the biogas generated, most of the producers showed interest and even enthusiasm on installing one in their properties. The producer No. 5 of Palma de la Cruz, due to his age, did not understand the purpose of the interview and the given information about biogas, showing no interest on biodigesters. Additionally, producer No. 7 was very skeptical of the viability of this kind of projects, specifically of their economic feasibility when there is no support from the government.

6.4 Field visit to installed biogas systems

The International Institute of Renewable Resources (IRRI) is a nonprofit organization that seeks to spread the use of environmentally friendly technologies in low-income communities. They have developed a biogas system called “Sistema Biobolsa”, that is basically a bag-type biodigester. The focus of their system is small scale farms that can use biogas for cooking and the digested manure (“biol”) as fertilizer for their crop lands (IRRI, 2012).

IRRI installed its first biogas system in 2007 in the State of Jalisco. In 2011 they started to produce biodigesters on a commercial scale. Hitherto, they have installed biogas systems in 16 Mexican States and in different countries of Latin America, including Peru, Nicaragua, Ecuador, Honduras and Costa Rica. They have created biogas programs in agreements with the government of Puebla, city councils of other municipalities and private companies like Nestle and Kellogs to install biodigesters in small scale farms and slaughterhouses (Eaton, 2012).

As part of their activities, they impart workshops where they give general information about biogas systems, show the installation process of a biodigester and offer visits to farms that have a biogas system already functioning. The course is given in the Tlaxcala Institute of Technology (ITAT), which is located in the border between the States of Tlaxcala and Puebla. Figure 12 shows a functioning biobolsa system located on the ITAT installations.

Figure 12 Functioning biobolsa system located in Tlaxcala, Mexico

When a system is sold, the IRRI technicians install the complete system, but the farmer has to dig the ditch where the biodigester is going to be placed. The measures of the ditch will depend of the size of the biodigester to be installed, and it must have a slope of about 45 degrees, with a shape as the one illustrated in Figure 13.

Figure 13 Shape of the pitch needed to place the biodigester

In addition to the pitch, the farmer needs to construct an inlet pit to load the manure into the biodigester (Figure 14, a) and an outlet reservoir for the digested material that is going to be used as a fertilizer (Figure 14, b). It is recommended that the inlet pit contains a slope and a mesh in order to remove rocks and other materials mixed with the manure that could plug or damage the biodigester.

(a)

(b)

Figure 14 Inlet pit with slope (a); outlet reservoir for digested manure (b)

The “Sistema Biobolsa” is sold as a modular system that includes everything necessary for its installation, and it includes:

- Liner: a geotextile, made of a polyethylene or polypropylene fabric. It is used to cover the ditch where the biodigester will be placed; it helps to isolate the biodigester in order to keep a stable temperature, even in case of rain.
- Bag-type biodigester: of tubular shape, it is constructed with geomembrane, a geosynthetic material made of impermeable membranes; this material is flexible, resistant to UV radiation and presents very good endurance to punctures. Geomembrane materials are guaranteed for 20 years average.
- Biogas collector: is a geomembrane bag that functions as a biogas storage tank.
- Tubes: made of polyethylene, to conduct biogas from the biodigester to its final use.
- Pipes: PVC pipes for inlet and outlet of manure.
- Filter: iron fiber is used to remove H_2S from biogas.

The volume of the biodigester will depend on the manure load and the hydraulic retention time. When fed to the biodigester, manure must be mixed with water in order to stimulate anaerobic conditions and to help the matter flow throughout the system. When designing a biodigester, it is very important to consider the following criteria:

- For dairy manure, the recommended manure-water ratio is 1:3.
- The total load must occupy 75% of the biodigester´s volume, the remaining 25% will be occupied by biogas

Figure 15 shows a diagram of a bag-type digester with its main components.

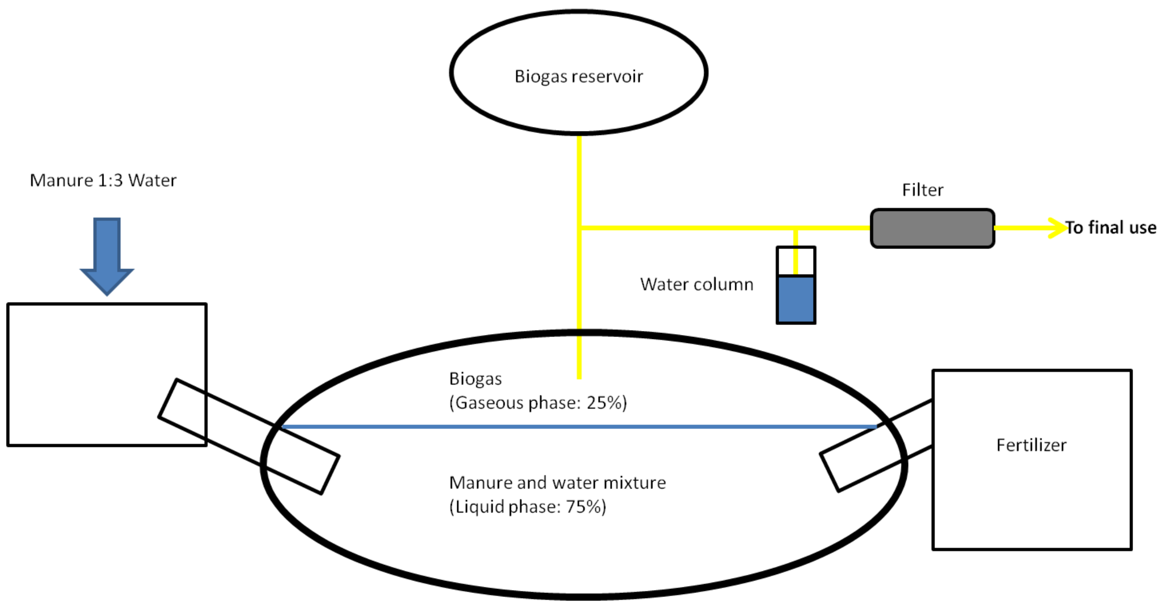

Figure 15 Bag-type biogas system diagram

The "biobolsa" system operates with a pressure between 20 and 30 cmH_2O, equivalent to approximately 2 to 3 kPa. The biodigester must be located as close as possible to the point of use to have a good gas pressure. The recommend distance is of 1 m/cmH_2O; in this case, the maximal distance would be between 20 to 30 meters (Eaton, 2012).

As mentioned before, the proportion of methane in biogas varies between 60 and 75% and contains other gases like steam. When the biodigester is not located next to the point of use, the steam in biogas could condensate in the tubes, preventing the biogas to burn. In this case, a water trap should be placed before the burner.

6.4.1 Installation of a bag-type biodigester

As part of the field visit, a biogas system with a volume of 10 m^3 was installed on a dairy farm located in a village near the municipality of San Martin Texmelucan, of the State of Puebla. The farm had about 15 cows and 6 calves, and before the installation, the manure was piled up as a solid outside the property. In the following pages, the installation process is illustrated.

1. Once the ditch has been excavated, make sure that it is properly level and empty (Figure 16).

Figure 16 Pitch ready for biodigester installation

2. The ditch is covered with the geotextile liner. The position of the liner is secured by covering its sides with sand (Figure 17).

Figure 17 The geotextile liner is placed on top of the ditch

3. The biodigester is placed inside the ditch and unrolled in top of the liner (Figure 18).

Figure 18 The bag-type biodigester is placed inside the ditch

4. Once the biodigester is properly placed inside the ditch, the tubes for the biogas outlet are connected (Figure 19).

Figure 19 Biogas tubes are connected to the biodigester

5. When all the system has been completely assembled, the biodigester starts to be loaded with water and fresh manure, avoiding sand, straw and rocks to get into the system (Figure 20).

Figure 20 Manure loading to the biodigester

Once the biodigester is full, 30 days (hydraulic retention time) must pass before the next load; after that time, the feeding will be done on a daily basis. Furthermore, the biogas collector is not installed until the biodigester starts to inflate, which is a sign of biogas being generated and a proof of the system to be sealed. Once the biogas starts to flow through the tubes to the point of use, the burner is installed in the user´s kitchen or to a special water boiler heated by biogas.

6.5 Mathematical model results

After collecting all the data of the visited farms, calculations were made using the Climate Action Reserve model. The model helped to estimate the emissions that are generated by the current identified manure management practices, as well as the potential of methane generation if a biogas system was installed in each of the farms.

6.5.1 GHG emissions due to current manure management practices

As mentioned before, dry lot systems were the only manure management practice identified on all the seven visited farms. Dry lot is listed as a non- anaerobic system, so Equation 6 was used to estimate the current methane emissions and converted to tones of CO_2 equivalent. The following values were used for the calculations:

- Values from tables:

	Anaerobic treatment	
	VS_L	$B_{O,L}$
Cows	3.91	0.188
Bulls	2.87	0.1
Calves	2.02	0.1

- Methane conversion factor for non-anaerobic storage/treatment system (MCF): 1.5% for dry lot
- Annual average temperature of San Luis Potosi: 17˚C

The results obtained by the model are the following:

Table 16 Annual methane and CO_2 eq. emissions for dry lot manure management systems on the visited dairy farm

	Villa de Pozos			Palma de la Cruz			
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Annual CH_4 emissions (m^3)	3624.08	1489.54	2013.04	1691.38	1207.87	1529.90	483.25
CO_2 ton. eq.	54.57	22.43	30.31	25.47	18.19	23.04	7.28

This means, an average 40.24 m^3 of methane and 0.6 tones of CO_2 eq. per cow.

6.5.2 Biogas production potential of the farms

Considering that all the visited farms change their current manure management practices for anaerobic treatment systems, it is possible to estimate the methane production potential using Equations 1 to 5. Unlike the previous calculations that were made in an annual basis, for the methane production potential in anaerobic systems, the calculations were made in a monthly basis. The following data was used for the calculations:

- Values from tables

	Anaerobic treatment	
	VS_L	$B_{O,L}$
Cows	3.91	0.188
Bulls	2.87	0.1
Calves	2.02	0.1

- Annual average temperature of San Luis Potosi: 17˚C.
- Day by month: 30
- Constant values:
  - R : 1.987 cal/kg mol
  - E: 15175 cal/mol
  - T1: 303.16 K

The results obtained by the model are the following:

Table 17 Potential monthly methane production and CO2 eq. emissions savings by installing a biogas system on the visited farms

	Villa de Pozos			Palma de la Cruz			
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Monthly CH_4 emissions (m^3)	606.65	231.04	319.85	290.31	194.11	242.84	82.95
CO_2 ton. eq.	9.13	3.48	4.82	4.37	2.92	3.66	1.25

To be able to compare the methane emission differences between the anaerobic and non-anaerobic manure management systems, the results from the model are shown in Figure 21 on an annual basis.

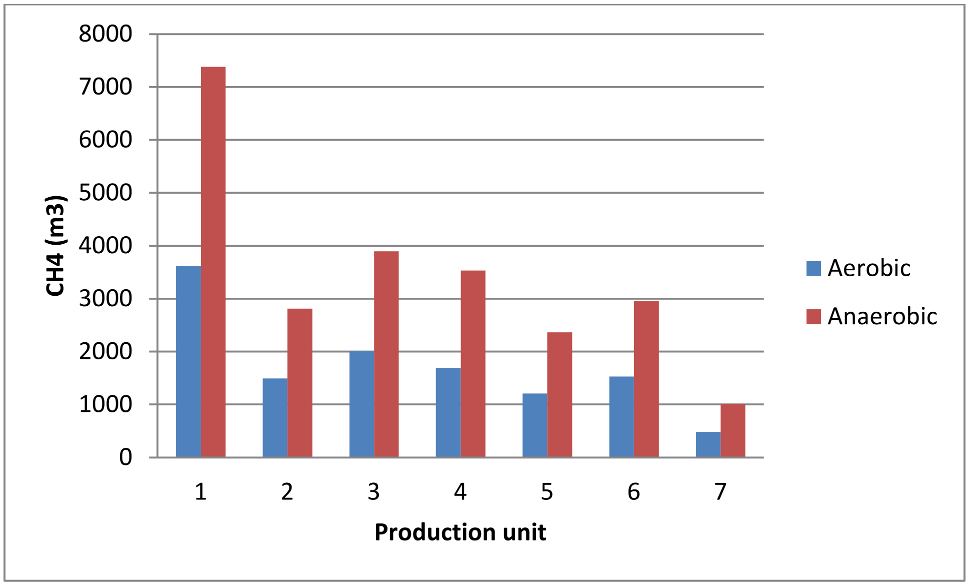

Figure 21 CAR model results: annual methane emissions in anaerobic and non-anaerobic manure management systems of the visited production units

6.6 Potential uses of biogas

Biogas, due to its high methane content, can be used as a fuel with different purposes. The easiest way of using the biogas generated with manure, is to use for cooking or heating by direct combustion. Nevertheless, on the visited farms, the production units were not next to the family house, making this option not viable. In the other hand, because of their high expenses in electricity, the best option for the visited farms would be to use biogas as a substitute of gasoline or diesel to run an electricity generator.

As mentioned before, some of the visited farms already have a gasoline generator or operate their milking machines directly with either gasoline or diesel. However, conventional gasoline generators would need to be modified to run on biogas, and that would not guarantee a good performance. In this case, it would be necessary to acquire a special generator that can run with biogas.

Considering that all the farmers own the same milking machine with the following specifications:

- Capacity of 4 cows at a time
- Milks 60 cows in 2 hours
- 2 HP electric engine

According to the number of cows present on each production unit and assuming that each cow is milked twice a day, the milking machine would be operating the following hours per day:

Table 18 Time required for milking

	Villa de Pozos			Palma de la Cruz			
	1	**2**	**3**	**4**	**5**	**6**	**7**
Number of cows	90	37	50	42	30	38	12
Hours needed for milking	6.0	2.5	3.3	2.8	2.0	2.5	0.8

In order to calculate the electricity generation potential with the generate biogas, the following considerations were made:

- A cubic meter of methane is equivalent to a cubic meter of natural gas
- Net calorific value of natural gas: 33.91 MJ/m3
- Net calorific value of gasoline: 31.61 MJ/ liter
- 3.6 MJ = 1 kWh
- 1 HP = 0.745 kW

Table 19 Potential daily electricity generation with biogas

	Villa de Pozos			Palma de la Cruz			
	1	**2**	**3**	**4**	**5**	**6**	**7**
CH_4 m^3/day	20.22	7.70	10.66	9.68	6.47	8.09	2.76
kWh/day	190.48	72.54	100.43	91.15	60.95	76.25	26.04
Hours running a 2 HP engine (30% efficiency)	38.31	14.59	20.20	18.34	12.26	15.34	5.24
Equivalent of gasoline L/day	21.69	8.26	11.44	10.38	6.94	8.68	2.97

Comparing results from Table 18 and Table 19, the potential capacity of electricity generations surpasses greatly the electricity needs for milking. However, it is important to consider that the estimated potential are ideal values and in practice the real biogas yields could be lower. Even so, all the production units could run their milking machines entirely with biogas and have surpluses for other uses like lighting, refrigeration and water pumping, which would imply big savings in terms of gasoline and electricity consumption.

If after covering all the electricity need of the farm there still are surpluses, it would be necessary to get an special permission from the CFE to be able to connect to the transmission network and sell the surpluses to the CFE. Another option would be to dimension the biodigester to cover the electricity needs of the farms instead of to give treatment to the totality of the manure.

6.7 Economic feasibility analysis

According to the mathematical model, there is an important biogas production potential in all the visited farms, but it is necessary to analyze if the economic benefits obtained by a biogas system would justify the investment. As shown in the previous section, it would be feasible to generate electricity with the biogas generated in the visited dairy farms. Table 20 shows the costs of a "biobolsa" system by capacity; the prices include all the material and the installations costs.

Table 20 Prices of modular biogas systems

Capacity (m^3)	No. of heads	kWh potential	Price (pesos)
4	1	1.77	15,572
6	2	3.53	17,660
8	3	5.30	23,858
10	4	7.06	27,222
12	5	8.83	28,382
16	7	12.36	31,482
20	9	15.89	31,002
25	12	21.19	43,730
30	15	26.29	52,150
40	20	35.32	56,790

In addition to the biogas system, the costs of the electricity generation have to be considered. For the unit operations like the ones visited with low energy needs, a small, low power biogas-run generator is enough. There exists portable biogas generator that can be placed near the biodigester to have good gas pressure, and stored after use. Figure 22 shows a model proposed to be used with the bag-type biodigester.

Price: 500 USD/6500 MXN
Rated power: 2-6 kW
Max. power output: 7 H.P.
Output: AC single phase
Life period: 15-20 years

Figure 22 Portable biogas generator

In order to apply the NPV method, it is important to determine several parameters:

- The life period of the biodigester and the generator is 20 years (t)
- The recoverable value at the end of their life period is cero
- The minimum rate of return expected of this project is 20% (i)
- The generator will produce enough energy to run the milking machines and a little surplus, but not enough no cover the electricity requirements of the refrigerators
- The saving on electricity or gasoline bills will be consider as the cash flows
- Maintenance costs were neglected

The possible saving of using the digested manure as a fertilizer were not taken into account as all of the visited production units have agriculture as a secondary activity and their fertilizer expenses are not very high. Although it was not part of this analysis, the digested manure could also generate incomes when sold as fertilizer to other farmers to be applied on their crop lands.

Table 21 Net present value results for 6 biogas investment projects

Community	No.	Energy uses	Investment costs	Annual cash flow	No. of heads	Biogas system (m3)	NPV
Villa de Pozos	1	Electricity	$63,364	$24,000	90	40	$53,506
	2	Gasoline	$58,714	$12,000	37	30	-$279.04
	3	Electricity	$63,364	$10,000	50	40	-$14,668
Palma de la Cruz	4	Electricity	$63,364	$21,000	42	40	$38,897
	6	Electricity	$58,714	$12,000	38	30	-$279.04
	7	Electricity	$50,294	$10,000	12	25	-$1,598

Only two of the analyses projects area economically feasible, as they present positive NPV values; the four remaining projects, with negative NPV values, would not be recommended. The best applications for biogas systems with electricity generation would be on those farms with more than 40 dairy cows and electricity expenses higher than $20,000 MXN a year. The minimum biodigester size advisable for electricity generation would be 40 cubic meters.

However, the previous calculations are just estimations based on the information given by the farmers, so the precise electricity expenses would need to be known in order to make a more reliable analysis. Furthermore, the minimum rate of return expected of 20% was set assuming that the farmers would anticipate a minimum profit from their investment, but for this particular project, having a lower rate of return would still make it acceptable when considering its multiple benefits.

7 Conclusions

Livestock production does not have a big impact on neither San Luis Potosi nor Soledad de Graciano Sanchez economies. However, the dairy farms located on these municipalities contribute largely to the State´s milk production, helping to cover the region´s demand of dairy products. Furthermore, these farms represent the livelihood of more than 500 families which engage to dairy livestock.

Mexico identifies manure management as the second source of methane emissions on the agricultural sector; nevertheless, except of some good practices recommendations, there are no specific programs or regulations that could help mitigate the GHG emissions related to manure management practices. Some federal States with high livestock population has started to include the manure subject on their local laws, since it has become both a health and environmental risk. This is not the case of San Luis Potosi given that the livestock density in the region is not high.

Methane emissions from manure increase under certain conditions. Management systems like anaerobic lagoons stimulate biogas production, thus increasing GHG emissions to the atmosphere. Covered anaerobic lagoons or biodigesters capture the biogas generated, avoiding GHG emissions and making possible to use biogas as a fuel.

Biogas systems as a renewable energy source have been used for many years all over the world. In Mexico, the use of biogas is quite recent and has only started to be promoted by the government since 2008 as a result of the energy reform. Since that date, biodigesters have been installed with governmental support in large dairy and swine production units. Small scale farms have not been benefited from this kind of public projects. On San Luis Potosi, there has only been installed one biogas system statewide.

According to the available data from the last agricultural census, most of the dairy farms located in the municipalities of San Luis Potosí and Soledad de Graciano Sánchez are small scale. None of the consulted institutions (SAGARPA, SEMARNAT, SEDARH, and INEGI) have information related to manure management practices of this region, so personal inspection of dairy production units was necessary to collect information.

The observations made on the field trips show that dry lot is the most common manure management system and unlike the common practice of applying manure to crop lands as fertilizer, all of the visited farms sell or give away manure to brick factories which collect the manure and clean the pens.

All of the interviewed producers said that milk production is the main activity from which they obtain incomes. At the same time, the producers expressed to have financial problems due to the several expenses related to the activity and the low milk prices. Although their farm provides them of livelihood, their life quality could be greatly improved.

Energy consumption represents an important expense in almost every productive activity. On dairy farms, the energy needs are diverse but most of them are covered with either electricity or gasoline. Energy is used for water pumping, lighting, milking machines and milk refrigeration. Most of the visited farmers have access to the electricity network and make use of it. Some of they knew that biogas can be obtained from manure and that electricity can be generated from it. All of the farmers expressed interest in installing a biogas system if it would reduce their energy expenditure.

All seven visited production units are left out of current public programs due to their small size and limited economic possibilities. Private institutions have taken the initiative of spreading biogas technologies in small scale farms in Mexico. Nowadays, the most common technology for Latin America is modular bag-type biodigesters. The work of institutions like IRRI has demonstrated that it is both technically and economically feasible to incorporate biogas systems to small scale dairy farms, benefiting the producers by providing them with a manure management treatment system, a renewable energy source and a good quality fertilizer. Therefore, this kind of system is advisable for the study case: small-scale dairy farms located on the suburb areas of San Luis Potosi City, due to its low cost, durability and installation simplicity.

In order to assess the biogas production potential of the visited farms in San Luis Potosi, the Climate Action Reserve mathematical model was used. The results showed that the methane emissions from the manure of 40 cows have electricity generation potential, so even small-scale farms are good candidates for biogas systems. It is important to consider that the model only gives estimate values and that the actual biogas yields depend highly on the site condition, system type and operation mode.

Additionally, the technical feasibility of the project depends greatly on water availability as its demand increases for the biodigester needs. Water supply has not been an issue in the specific case of the visited farms, but before undertaking a biogas project, it is important to consider that San Luis Potosi is an arid region and has recently experienced serious droughts.

Only the environmental benefits that involve the installation of a biodigester should be enough incentive to spread its use. However, the economic factor represents a big limitation when the producer is the one that has to make the investment. The economic analysis showed that a biogas system for electricity generation is only feasible for those production units with more than 40 heads and high energy requirements. These results are for a specific use of biogas and biodigester type and it does not rule out the possibility of other kind of systems to be economically viable, like less-expensive plastic foil biodigesters or making direct use of biogas for heating or cooking.

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Annex A. Structured interview to dairy farms located in the municipalities of San Luis Potosi and Soledad de Graciano Sanchez

Note: The original questions in Spanish as asked to the producers are presented first, followed by the corresponding English translation.

Ubicación: *(Location)* Fecha de aplicación: *(Date)*

Participó en el último Censo Agropecuario *(Did you take part in the last agricultural census?)*

Forma parte de la Unión Ganadera o alguna otra asociación *(Are you a member of the livestock producers union or any other association?)*

Tipo de sistema: (*System type*)

I. Información sobre el ganado (*Livestock information*)

- Cuántas cabezas tiene actualmente? (*How many heads do you own?*)
  - Vacas lecheras *(dairy cows)*
  - Toros *(bulls)*
  - Vaquillonas/Novillos *(Calves/Haifers)*
- En promedio, con cuántas cabezas cuenta normalmente? (*What is te avarage number of heads you normally have?)*
- Cuenta con algún otro tipo de animales en la granja? *(Do you have any other kind of animal in the farm?)*
-

II. Información sobre el tipo de manejo del estiércol (*Information regarding manure management*)

- Qué hace con los desechos de los animales? *(What do you do with manure?)*
  - Pastoreo *(Range grazing)*
  - Esparcimiento diario *(Daily spread)*
  - Almacenamiento sólido *(Solid storage)*
  - Corral de engorda *(Dry lot)*
  - Abono líquido *(Liquid/Slurry)*
  - Quemado para combustible *(Burned for fuel)*
  - Laguna anaeróbica descubierta *(Uncovered anaerobic lagoon)*
  - Almacenamiento en fosas por debajo de las instalaciones de confinamiento *(Pit storage below animal confinment)*
  - Cama profunda *(Deep beding)*
  - Composteo *(Compost)*
  - Digestor anaeróbico *(Anaerobic digester)*

- Existe algún tipo de control sobre el manejo de los desechos? (Visitas de la SAGARPA, SEMARAT) *(Is there any kind of manure management control by the government? Agriculture or Environment ministry periodic visits)*
- Tiene conocimiento de algún tipo de "buenas prácticas" para el manejo de los desechos? (SAGARPA, SEMARNAT*) (Do you know any kind of „good practices" for manure management? Information given by either the Agriculture or Environment Ministry)*

III. Información sobre los usos de energía *(Information regarding energy uses)*

- Que usos de energía tiene en la granja? *(Which energy uses do you have in the farm?)*
    - Gas L.P./ Gas natural/Leña *(L.P. gas/Natural gas/Fire wood)*
        - Cocinar *(Cooking)*
        - Calentar agua *(Water heating)*
    - Electricidad *(Electricity)*
        - Bombeo de agua *(Water pumping)*
        - Iluminación *(Lighting)*
        - Maquinaria *(Machinerie)*
        - Electrodomésticos *(Appliances)*
    - Diesel/Gasolina *(Diesel/Petrol)*
        - Transporte *(Transportation)*
        - Maquinaria *(Machinerie)*
- Aproximadamente a cuánto ascienden sus gastos mensuales de energía? *(Approximately, how much do you pay monthly for energy?)*
    - Gas L.P./Gas natural/Leña *(L.P. gas/Natural gas/Fire wood)*
    - Electricidad (Electricity)
    - Diesel/Gasolina *(Diesel/Petrol)*
- Tiene problemas con el abastecimiento de energía? *(Do you have any problem with energy supply)*

IV.* Información sobre el uso de agua *(Information regarding water usage)

- Tiene problemas con el abastecimiento de agua? *(Do you have problems with water supply?)*
- De dónde proviene el agua que utiliza? *(The water you use, where does it come from?)*

V. Información socio-económica *(Socio-economic information)*

- Cuál es el destino de la leche que produce? *(What is the destination of the milk you produce?)*
    a. Venta informal *(Informal sale)*
    b. Surte a alguna compañía *(Supply for a company)*

c. Consumo propio *(Self-consumption)*
d. Otro *(Other)*

- La producción de leche es la actividad principal con la cual obtiene recursos? *(Is milk production the activity from which you obtain most of your incomes?)*
- Cuenta con terrenos de siembra? *(Do you own crop land?)*
- Cuenta con algún tipo de apoyo del gobierno? *(Do you receive any kind of governmental support?)*

VI. Conocimiento de sistemas de producción de biogás *(Knowledge regarding biogás production systems)*

- Alguna vez ha escuchado usted que se puede producir gas a partir de los desechos de los animales, y que este gas se puede utilizar para cocinar o hasta para producir electricidad? *(Have you ever listened that it is possible to produce gas from animal manure and that it is possible to burn this gas for cooking or even for electricity production?)*
- Si se pudiera ahorrar dinero con eso, estaría usted interesado en instalar uno de estos sistemas en su propiedad? (*If you could save money by installing one of those systems, would you be interested?)*

Annex B. Climate Action Research: Tables for the Mathematical Model

Table 22 Volatile Solids and Maximum Methane Potential by Livestock Category

Livestock category (L)	VS_L (kg/head/day)	$B_{o,L}$ (m^3 CH_4/kg VS)
Dairy cattle		
Dairy and non-milking dairy cows (in intensive systems in cool and temperate climate with an average annual temperature between 8^{o}C and 23^{o}C)	3.91[a]	0.188[b]
Dairy and non-milking dairy cows (in intensive systems in warm climate with an average annual temperature warmer than 24^{o}C)	4.46[a]	0.188[b]
Heifers (intensive systems – feedlot cattle)	2.02[c]	0.17[c]
Bulls (grazing)	2.87[c]	0.10[c]
Calves and heifers (pasture or grazing in semi-intensive systems or dual-purpose)	2.14[c]	0.10[c]
Heifers (pasture or grazing in semi-intensive systems or dual-purpose)	2.14[c]	0.10[c]
Cows (grazing in semi-intensive systems in cold and temperate climate with an average annual temperature between 8^{o}C and 23^{o}C)	2.86[a]	0.10[c]
Dual-purpose cows (grazing in extensive systems in cold and temperate climate with an average annual temperature between 8^{o}C and 23^{o}C)	1.33[a]	0.10[c]
Dual-purpose cows (grazing in extensive systems in warm climate with an average annual temperature warmer than 24^{o}C)	1.51[a]	0.10[c]

Table 23 Livestock categories and typical average mass

Livestock category (L)	Livestock Typical Average Mass (TAM) in kg
Dairy cattle	
Dairy and non-milking dairy cows (on feed in intensive systems)	550
Heifers (on feed in intensive systems)	415
Bulls (grazing in large areas)	450
Calves (semi-intensive with grazing or dual-purpose in extensive systems)	151
Heifers (semi-intensive with grazing or dual-purpose in extensive systems)	300
Cows (semi-intensive with grazing or dual-purpose in extensive systems)	425