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Anaerobic Biodigester Technology in Methane Capture and Manure Management in Mexico

The History and Current Situation

Final Report

MEXICO LOW EMISSIONS DEVELOPMENT PROGRAM (MLED)

FIXED OBLIGATION GRANT (FOG) NUMBER 1106595

BY

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LEGAL ADVISORY

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Executive Summary

The purpose of this study is to evaluate the history and current situation of anaerobic biodigester (AD) technology in methane capture and manure management in Mexico where livestock activities are carried out in 110 million hectares. Because scale is a critical factor for determining technological viability, commercial availability and financial feasibility, for the purposes of this study the Mexican biodigester population was divided into three strata: 1) Domestic Sector biodigesters are less than 25 m^3, 2) Productive Sector biodigesters are greater than 25 m^3 but less than 1,000 m^3, and 3) Industrial Sector Biodigesters are greater than 1,000 m^3.

The Domestic Sector can be characterized as small scale backyard farms (<2 Ha) that form a part of an integrated household economy of low income, rural and marginalized communities. Systems in this sector have largely been spearheaded by a handful of key players in the country including PESA Mexico, the W.K. Kellogg Foundation, Kiva, and IRRI Mexico among others.

The Productive Sector refers to anaerobic biodigester technology that is implemented in small and medium sized businesses and family farms that are neither domestic nor industrial in scale. In recent years, the Productive Sector has been identified as an underserved area in the global market and particularly in Mexico where we see only 109 systems in the country as of September 2014.

The Industrial Sector systems are exclusively implemented in large agro-industrial livestock operations that have thousands or tens-of-thousands of animals across all phases of the growth cycle. These systems have been bolstered by financing through the Clean Development Mechanism (CDM) and the Secretary of Agriculture and Rural Development of Mexico (SAGARPA) and their financing trust (FIRCO). For this report, IRRI Mexico conducted a survey and evaluation of existing domestic, productive and industrial scale livestock manure management biodigesters. Surveys were conducted over a nine week period ending on April 15, 2015.

The results of the survey reveal that biodigesters are performing well in general across all sectors but significant improvements can be made in order to increase the benefits. Users in the Domestic Sector make use of biogas for household cooking and water heating and often see benefits from the effluent as a fertilizer. For the Productive and Industrial Sectors benefit from the use of biogas as an energy source that displaces LPG and electricity consumption as well as financial savings from the use of the biodigester effluent as fertilizer. Greenhouse gas emissions reductions are significant across all market sectors and increase linearly with volume of biodigester. Several conclusions and recommendations for each market sector were derived from this study.

Conclusions and Recommendations for the Domestic Sector

Domestic Sector users with a 4 -6 m^3 system save on average $235 MXN per month, whereas the users with the larger system on the market (20 m^3) save on average $1,100 MXN per month. A 4m^3 system produces an annual average GHG ERs of 1.36 MT of CO2e, whereas the larger system on the market (20 m^3) produces an annual average GHG ERs of 1.18 MT of CO2e (see Figure 1).

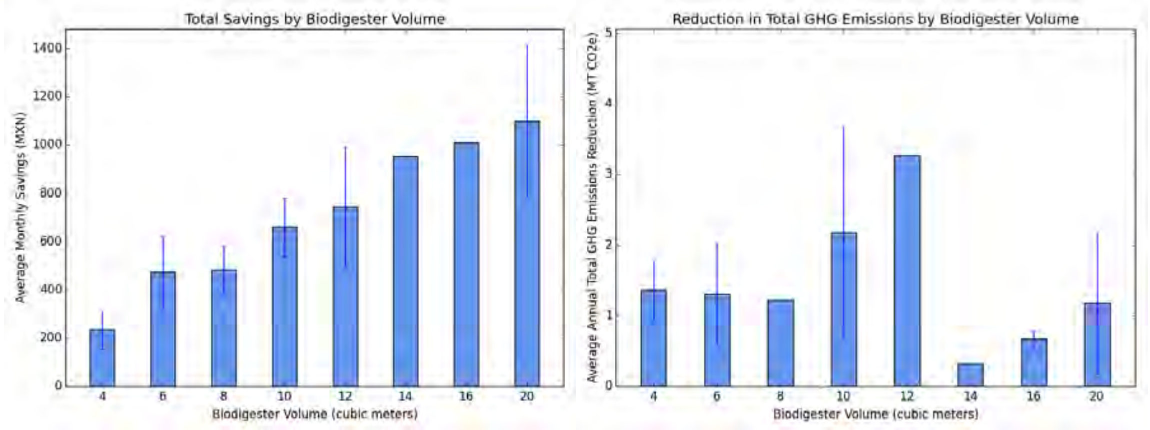

Figure 1: Domestic Sector Total Savings ($MXN / year) across a range of volumes (left) and Domestic Sector Total GHG Emissions Reductions across a range of volumes (MT GHG / year) (right)

Because biodigesters in the Domestic Sector only treating 27% of the manure that is being produced in backyard farms and the majority of are not operating at full capacity, it is recommended that incentives and follow up programs are implemented to encourage users to increase the amount of manure that they treat in the digester.

Particularly in the Domestic Sector, GHG emissions reductions are significantly higher in the systems when the users are able to displace woodfuel consumption. Given that the highest return on GHG emission reductions per program dollar invested is found when biogas production displaces woodfuel consumption, if the goal is to reduce emissions of GHGs, a program should target backyard farms where woodfuel is the primary domestic fuel supply and is harvested unsustainably (i.e. not being regenerated). Because this demographic is highly marginalized and unable to pay for a system in most cases, it is recommended that these program be highly subsidized (>90%).

Because financial benefits increase significantly when users are able to displace LPG consumption and / or chemical fertilizer applications to crops, if the goal is to generate financial benefits, a program should target backyard farms that are able to displace LGP consumption and chemical fertilizer usage. Given that these systems generate significant financial benefits, the subsidy levels can be lower perhaps around 50%. However, the upfront cost, even at 50% subsidy will still present a significant barrier to this demographic. Therefore, subsidies should be combined with financing mechanisms that can reduce the upfront cost though micro-loans that will smooth out the impact that the purchase on has on the household economy.

While the large majority (89%) of the systems in the Domestic Sector are “functioning well,” or “functioning well with minor problems,” 1% of the systems are not functioning because of simple problems that can be easily solved through basic maintenance and repairs and 10% are not operating because of lack of use or abandonment. Failed systems should be targeted by a technical assistance program that will provide additional training to users on basic maintenance and repairs. All biodigesters that are constructed of polyethylene should come with a patch kit and an instruction manual for how to repair common punctures and tears in the membrane. If the goal is to generate the highest overall (financial, social, climate and environmental), a program should be implemented to attend to the 11% of the biodigesters that are currently not operating. With a relatively small investment in technical assistance, most of these systems can likely be recovered.

Domestic Sector biodigester are working well, are experiencing high level of acceptance within beneficiary groups, and are generating a wide range of benefits, including environmental, financial, climate, and social benefits. These impacts can and should be scaled-up by implementing more biodigester programs. Increased funding should be allocated towards Domestic Sector programs in order to multiply these benefits to society and household economies, while mitigating climate change and reducing the environmental impacts of backyard farming operations.

Conclusions and Recommendations for the Productive Sector

Productive Sector users with a 25-40 m^3 system save on average $615 MXN per month, whereas the users with the larger system on the market (400-800 m^3) save on average $15,100 MXN per month. A 25-40m^3 system produces an annual average GHG ERs of 4.2 MT of CO2e, whereas a 400-800 m^3 produces an annual average GHG ERs of 618 MT of CO2e (see Figure 2).

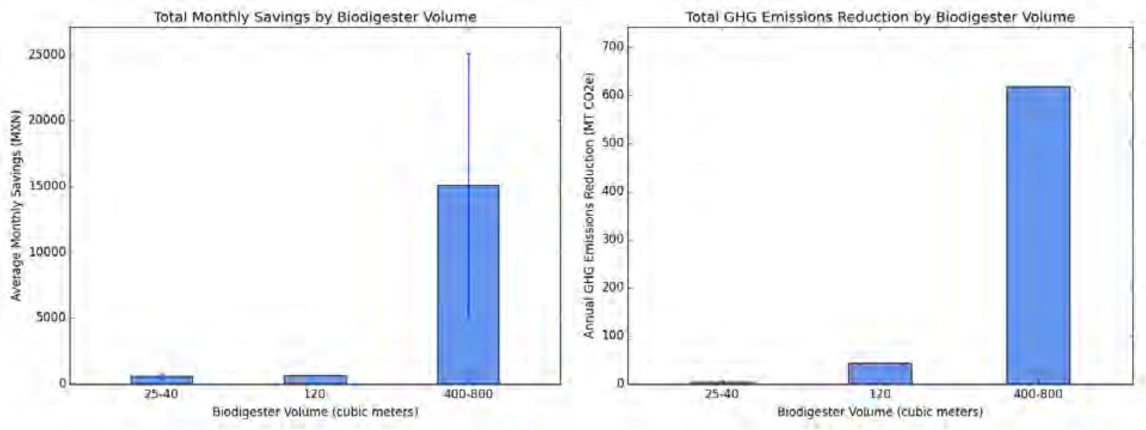

Figure 2: Productive Sector Total Savings ($MXN / year) across a range of volumes (left) and Productive Sector Total GHG Emissions Reductions across a range of volumes (MT GHG / year) (right)

The Productive Sector has received relatively little attention by government programs when compared to the Domestic and Industrial Sectors. This is reflected in the fact that the total number of systems installed in this sector is 109 compared to 799 and 1259 for the other sectors respectively. The survey results show that Productive Sector biodigesters are providing widespread benefits to farms in the medium-scale livestock sector and more programs should be designed to target this sector.

Within the Productive Sector (systems between 25 and 1,000 m^3) a gap exists between systems on the lower end of the distribution and systems on the higher end of the distribution. The large majority (83%) of the Productive Sector systems are less than 120 m^3 and are tubular type. Between 120 m^3 and 1,000 m^3 we see a change in technology type; we see a transition towards covered lagoon biodigesters as we move up the scale. In order to understand why this is the case we recommend conducting a study to generate information that will allow us to identify the barriers that have led to the sector to be relatively unattended. The study should illuminate the characteristics of this market sector and explore the benefits and drawbacks of applying different technology types such as tubular versus lagoon.

The systems in the higher end of the range (400-1,000 m^3) are underutilizing the biogas resource. In general they are simply destroying the gas through flaring and are not dedicating the gas to productive uses that could generate additional climate and financial benefits. Resources should be dedicated to promoting complementary technologies that can take advantage of the underutilized biogas in the Productive Sector. These technologies include: biogas pumps and motors to displace gasoline consumption, and in some cases biogas generators that can displace electricity consumption through a Net Metering contract with the National Electricity Commission.

While the large majority of the systems (82%) in the Productive Sector are "functioning well," or "functioning well with minor problems," 18% of the systems are not functioning because they had a technical issue that the user was not willing or able to solve such as leaks in the geomembrane, problems with humidity and digester clogging from the lack of periodic solids removal. These simple problems can be easily solved through basic maintenance and repairs. Failed systems should be targeted by a technical assistance program that will provide additional training to users on basic maintenance and repairs. Additionally, all biodigesters that are constructed of polyethylene should come with a patch kit and an instruction manual for how to repair common punctures and tears in the membrane. Furthermore, if the goal is to generate the highest overall impact (financial, social, climate and environmental), a program should be implemented to repair the 18% of the biodigesters that are currently not functioning in the Productive Sector. With a relatively small investment in technical assistance, most of these systems can likely be recovered.

Conclusions and Recommendations for the Industrial Sector

Industrial Sector users with a 1,000-10,000 m^3 system save on average $38,000 MXN per month, whereas the users with the larger system on the sector (>20,000 m^3) have no savings because they do not generate electricity nor displace fertilizer use. The 1,000-10,000 m^3 systems produce an annual average GHG ERs of 1,360 MT of CO2e, whereas the 10,000-20,000 m^3 systems produce an annual average GHG ERs of 2,640 MT of CO2e. However the systems larger than 20,000 m^3 produce an annual average GHG ERs of 1,370 MT of CO2e (see Figure 3).

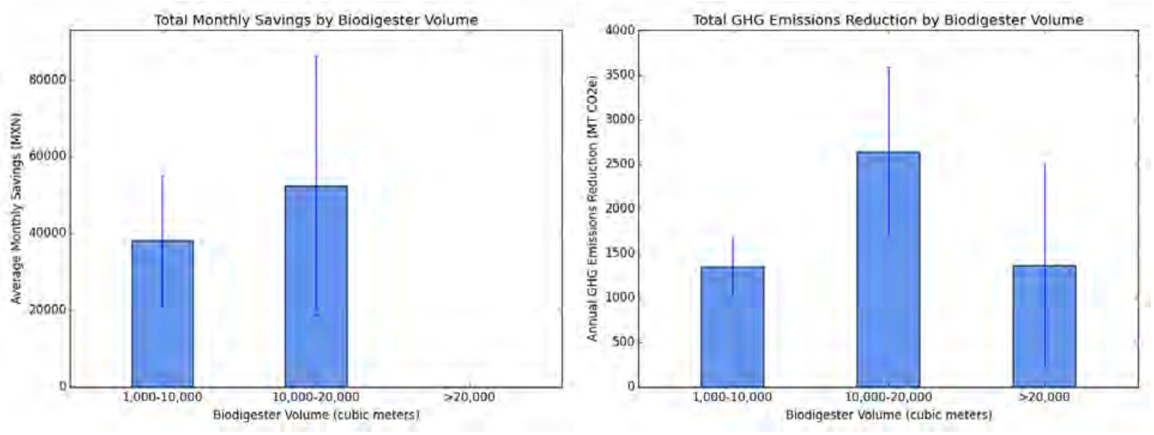

Figure 3: Industrial Sector Total Savings ($MXN / year) across a range of volumes (left) and Industrial Sector Total GHG Emissions Reductions across a range of volumes (MT GHG / year) (right)

The majority of the Industrial Sector biodigesters are not operating at full capacity because they are clogged from solids that have settled and hardened in the bottom of the lagoons. This is caused by a lack of frequent extraction and / or lack of agitation systems. Systems that are currently heavily clogged with settled solids that are hardened will need to be opened and cleaned out with heavy machinery (excavators and backhoes). For new and recently reactivated installations, it is recommended to install and use agitators and remove settled solids every 3-6 months. This will avoid hardening of the solids that causes the loss of operating capacity and the need to invest in expensive maintenance processes. Trainings, follow-up and technical assistance, particularly during the first few months of a biodigester operating, will improve the users' ability to properly operate and maintain their systems.

The majority (61%) of the Industrial Sector biodigesters are not generating the maximum financial and climate benefits because the biogas is not being put to a productive use. These systems destroy the methane through flaring (burning off). Promoting accessory technologies that allow the end user to displace the consumption of electricity or fuels onsite in order to maximize financial and climate benefits. These accessory technologies are biogas pumps and generators, as well as generators interconnected to the grid through Net Metering contracts with the National Electricity Commission.

The success or failure of an Industrial Sector biodigester is highly dependent on the financing mechanism, and financing mechanisms that do not provide financial benefits to the end user are more likely to fail. Regardless of potential revenue streams from selling of carbon credits, programs that promote biodigesters should maximize financial benefits to the end users by providing productive uses to the biogas that displace the consumption of fuels end electricity.

There is a massive amount of CO_2e abatement being generated by Industrial Sector biodigesters that is not being commercialized; this presents an opportunity to identify pathways for certifying and commercializing the CO_2e offsets.

Industrial Sector biodigesters are producing an excess of effluent that is not being utilized due to lack of demand and government regulations that prohibit applying the product. The liquid effluent and the separated bio-solids are valuable byproducts that should be commercialized as organic fertilizers and soil amendments.

Industrial Sector biodigesters, that are properly designed, operated and maintained, and where the biogas, effluents and solids are put to productive end-uses, are generating impressive financial, social, environmental and climate benefits. Increased government funding is needed to subsidize the purchase of Industrial Scale biodigesters and complementary biogas technologies.

Introduction

The purpose of this study is to evaluate the history and current situation of anaerobic biodigester technology in methane capture and manure management in Mexico, and was carried out by the International Renewable Resources Institute of Mexico (IRRI Mexico), for the United State Agency for International Development (USAID) for Component II of the project "Removing Barriers to Greenhouse Gas Mitigation in Medium Scale Agricultural Livestock Activities within Mexico." This project forms part of the activities being carried out by the Mexico Low Emissions Development Program of the USAID. The study seeks to highlight the successes and failures of this technology in the Mexican livestock sector through a comprehensive national survey, case studies and interviews with key players. The study would not have been possible without the collaboration of stakeholders in Mexico including SAGARPA (Secretary of Agriculture and Rural Development)[1], FIRCO (Joint Venture Trust of SAGARPA)[2], as well dozens of actors in the private and agricultural sector.

Background

In Mexico there is great potential for AD technologies to be used within agricultural livestock manure management. Livestock activities are carried out in 110 million hectares throughout Mexico, with 51% of livestock activities located in the southern and southeastern tropic region and the temperate central region of the republic.

There are an estimated 430,000 intensive livestock production units in Mexico (13% of the total livestock units), which are mainly devoted to poultry farming, pig breeding and cattle raising (beef and dairy). These units can meet the needs of 70 to 98% of the national market depending on the product and access to international markets (UNFCC, 2009). However, along with these intensive units, there exist another approximately 2.9 million livestock units in family backyard farms (*traspatios*) or in the form of extensive cattle raising. These units utilize low levels of technology and have poor access to healthy markets (SEMARNAT, 2008).

For this report, IRRI Mexico conducted a survey and evaluation of existing domestic, productive and industrial scale livestock manure management biodigesters in Mexico that includes a technical and economic evaluation of the performance, impact, and end-user perception of a statistically significant sample of the estimated 2,167 biodigesters that are catalogued in Mexico (as of September 2014). This survey and evaluation considers representative samples of systems based on age, geographic region, farm size, and investment structure. The evaluation focuses on identifying best practices, barriers, and useful case studies; all with the overall objective of providing concrete information of the role that biogas and AD manure management technology can have in GHG emissions reductions in Mexico and beyond.

The benefits of anaerobic digestion (AD) technologies for methane-capture include reductions in greenhouse gas (GHG) emissions and improvements in surface water quality. Benefits to users and their communities include reductions in odor and insect populations, the production of organic

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[1] Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (http://www.sagarpa.gob.mx)

[2] Fidecomiso de Riesgo Compartito (http://www.firco.gob.mx/)

fertilizer, and the generation of decentralized energy in the form of biogas or biogas-generated electricity. Depending on the user, this electricity can be sold to the National Electricity Commission under Net-metering contracts to generate significant economic impact in the farm economy.

Within these livestock farms, Mexico is home to over 9 million head of pig, over 23 million head of cattle and around 340 million poultry fowl, not considering other livestock (INEGI, 2009). It is estimated that, considering only confined livestock, around 61 million tons of manure and 3,552 million m^3 of livestock black water is produced in Mexico each year (INEGI, 2009). The majority of these farms do not manage this waste stream effectively and the ‘business as usual’ treatment method is usually to dispose of the manure in aerobic lagoons. This causes water contamination throughout the country from the nutrients within the waste that runoff into surface water bodies and climate change impacts through the generation of methane and other powerful GHGs from anaerobic fermentation processes (Financiera Rural, 2011).

Mapping the Three Market Sectors

For anaerobic biodigesters, the total volume of the liquid slurry anaerobic phase is linked to the volumetric flow of the waste stream being treated. The volume of a biodigester is defined, as a rule of thumb, as the total volume of slurry that is maintained in the anaerobic environment. The dimension of the biodigester is normally designed to process all of, or a portion of the total manure produced daily (m^3/day) from a given farm operation at the indicated water dilution levels. The user demographics of biodigester technology are primarily distinguished by farm size or animal population. As the farm increases in size, the user groups change. For example, a user of a biodigester applied in a backyard pig farming operation in an indigenous community in the Yucatan Peninsula is quite distinct from the users of a biodigester applied in a 15,000 head pig farm in the northern state of Sonora. Both technology and demographics of the end-users changes dramatically as farms move from simple backyard operations, to family farms with dozens or hundreds of animals, to large scale industrial livestock operations. Notably there is the underserved “Productive Sector” (medium scale) which is characterized more as family farms and businesses. For the purposes of this study we have divided the Mexican Biodigester population into three strata:

1. Domestic Sector Biodigesters are smaller than 25 m^3 in volume
2. Productive Sector Biodigesters are greater than 25 m^3 but less than 1,000 m^3
3. Industrial Sector Biodigesters are greater than 1,000 m^3

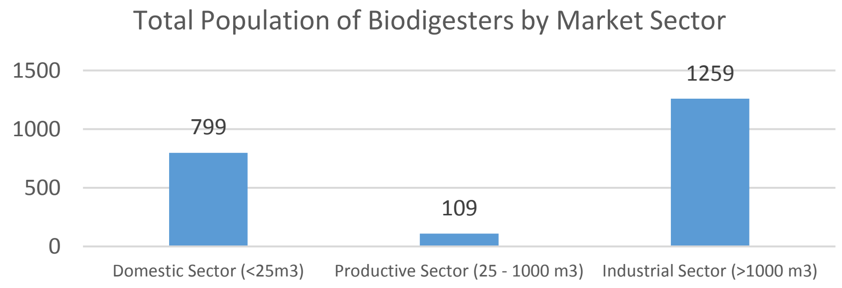

Figure 4: Total population by market sector.

Across all three sectors of the market, scale is a critical factor for determining technological viability, commercial availability and financial feasibility. The Domestic Sector benefits from several decades of experience with over 20 national level programs across the globe particularly in Asia, Africa and Latin America, with multilateral agreements and an ever increasing level of market stability and accessibility to technology providers and funding sources. A healthy range of technologies are available, and networks of experts, businesses and policy makers are able to share best practices and improve the viability and development impact of the technology. Massive opportunity and need for growth in the domestic area remain, but strategies and technologies for future growth have been demonstrated and replicated. On the other end of the spectrum, the Industrial Biogas Sector has a full plethora of complimentary technology options, competition among providers, government regulations and oversight, and international financing options through CDMs.

Domestic Scale Biodigesters in Mexico

The domestic biodigester sector can be characterized as small-scale backyard farms that form a part of the integrated household economy of low income, rural and marginalized communities. Approximately 2.9 million livestock units reside in family backyards or in the form of low-tech extensive cattle grazing and inefficient markets (SEMARNAT, 2008).

Image 1: Tubular modular polyethylene biodigester installed in a backyard farm by Sistema Biobolsa in partnership with the W.K. Kellogg Foundation and IRRI Mexico (2014).

For purposes of this study, the Domestic Sector is defined as digesters with less than 25 m^3 of volume. Biodigester programs targeting the domestic sector in Mexico have largely been spearheaded by a handful of key players in the country including PESA Mexico, the W.K. Kellogg Foundation, Kiva, and IRRI Mexico among others. As of September 2014 there were a total of 799 systems installed with heavy concentrations in the states of Puebla, Tlaxcala, Mexico, Queretaro, Hidalgo and Yucatan (see Figure 11).

Strategic Food Security Program (PESA)

PESA is the Strategic Food Security Program being implemented in marginalized communities throughout Mexico. The goal of the program is to increase food security through supporting income generation and food production at the community and household level by taking advantage of locally available resources through trainings and technical support. The program, in cooperation with the Food and Agricultural Organization (FAO), is operating in 23 Mexican states and was launched in 2005. This program has been a significant motor for the dissemination of a wide range of ecotechnologies including domestic scale biodigesters (see Figure 5).

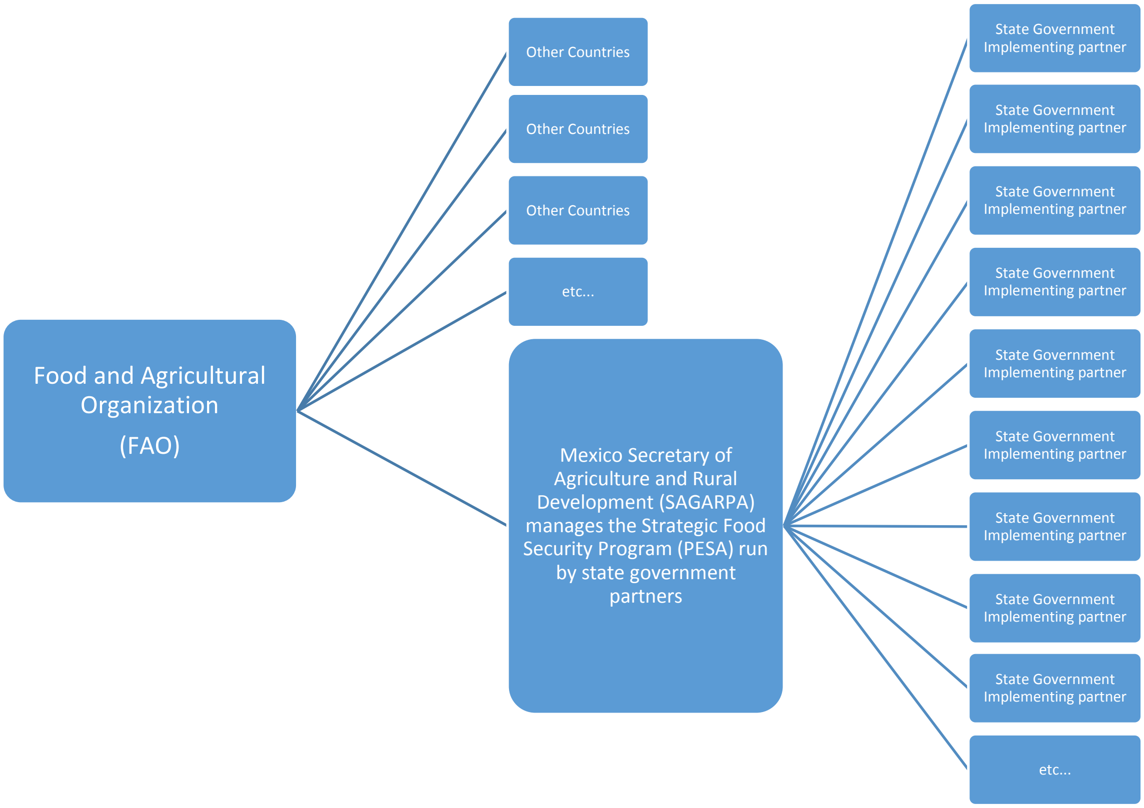

Figure 5: The Strategic Food Security Program (PESA) is sponsored by the FAO and operates through bilateral agreements in multiple countries. In Mexico, the Secretary of Agricultural and Rural Development (SAGARPA) manages the program through state implementing partners.

The vision of PESA in Mexico is "to create the conditions and capacities for families and rural communities to improve family farming, nutrition and income, and face the future with greater food security and improved livelihoods to assist them to overcome poverty gradually and progressively (SAGARPA, 2015)."

Image 2: Tubular modular polyethylene biodigester installed in a backyard farm as part of the Strategic Food Security Program (PESA) run by the Secretary of Agriculture and Rural Development (SAGARPA) in the state of Hidalgo.

The W.K. Kellogg Foundation

In 2013 the W.K. Kellogg foundation partnered with IRRI Mexico to implement a domestic scale biodigester program in rural marginalized indigenous communities in the Yucatan Peninsula. The program's stated goal was to "contribute to improving the health of families in Mani, Yucatan, Mexico by installing biodigesters and a program aimed to build capacities regarding the proper management of organic wastes. To-date around 100 domestic scale biodigesters have been installed in the Yucatan Peninsula through this program.

Image 3: Backyard pig farming operation in Mani, Yucatan. Typical household beneficiary of domestic scale biodigesters.

Sistema Biobolsa

Sistema Biobolsa, founded in 2010, is a Mexican social and environmental impact company that manufactures, distributes and installs tubular polyethylene biodigesters designed for small and medium scale farms. The company arose in a collaboration with the International Renewable Resources Institute of Mexico and in partnership with government and national and international foundations, has implemented essentially 100% of the domestic scale biodigesters in Mexico since their founding (799).

Kiva

Kiva (www.kiva.org) is a US based non-profit organization with a mission to connect people through lending to alleviate poverty. Leveraging the internet and a worldwide network of microfinance institutions, Kiva lets individuals lend as little as $25 USD to help create opportunity around the world. Kiva works with microfinance institutions on five continents to provide loans to people without access to traditional banking systems. One hundred percent of the loans are sent to these microfinance institutions, referred to as Field Partners, who administer the loans in the field. In 2012 Kiva partnered with Sistema Biobolsa to provide micro-financing to small farmers in Mexico to offset the upfront cost of a system. These 0% interest loans are valuable to rural families that could never otherwise afford the biodigester, no matter how much they might save in the long run. Kiva loans provide a source risk-tolerant, flexible capital to help these farmers purchase Sistema Biobolsa equipment. As of May 2015, 398 families have accessed zero interest loans through this partnership and have received $ 392,400 USD in financing towards the purchase of Sistema Biobolsa equipment (www.kiva.org/partners/226).

Biodigester specifications and typology

All of the digesters in the domestic sector are tubular polyethylene modular continuous flow type biodigesters. The manure decomposes anaerobically and produces methane which inflates the bag with gases which are then piped to the home for cooking, heating of water, or other uses. These systems typically do not generate enough gas to produce significant amounts of electricity, and the usual end uses of the fuel is heating water or cooking.

Figure 6: Typical domestic scale biodigester installed by Sistema Biobolsa in the state of Hidalgo with funding from SEMARNAT (PESA).

These systems are the most economical type of digesters on the market and work well for operators who need to minimize their capital costs. They are also best suited for warm climates since there is no thermal insulation around the digester to ensure that its contents stay at the requisite 35-41° C (Penn State Extension).

The Mexican company Sistema Biobolsa (www.sistemabiobolsa.com) is responsible for all of the digesters installed in this sector. The models of digesters from this company range from 4 – 20 m^3. This company has worked extensively with IRRI and KIVA projects. Kiva is a microfinance program that allows the public to donate money that is loaned and re-loaned to individuals that show they have a sound plan for investing of the money.

Productive Sector Biodigesters in Mexico

The Productive Sector refers to anaerobic biodigester technology that is implemented in small and medium sized businesses and family farms that are neither domestic nor industrial in scale. The term “Productive” is used in this report because it combines several previously used definitions of biodigester categories such as “Biogas for Productive Use,” “Medium Scale Biogas,” “Biogas for Business,” and “Institutional Biogas,” which are not exclusively delimited by capacity or volume. Nevertheless, for the purposes of this study, we have defined the “productive sector” as biodigesters greater than 25 m^3 and less than 1,000 m^3.

Image 4: 80 cubic meter tubular modular polyethylene biodigester at a medium scale hog farm in Yucatan (2013).

In recent years, the productive biogas sector has been identified as an underserved area in the global market and particularly in the Mexican market where we see only 109 systems installed in the country as of September 2014 (SNV, 2014) (Figure 7). Considering medium scale swine farms, beef production units, dairies and slaughterhouses there is the potential for the installation of between 300,000 and 500,000 productive biogas units in Mexico. Often referred to as the "missing middle," this sector has not been actively targeted in national and international development plans despite the fact that systems at this scale (25-1,000 m^3) have been proven to be technically and financially feasible. Biodigesters at this scale offer a uniquely comprehensive solution to a wide range of interconnected challenges in the medium scale agricultural livestock sector such as inefficient and expensive costs of operation, pollution of local waterways, climate change as well as dependency on petroleum based chemical fertilizers.

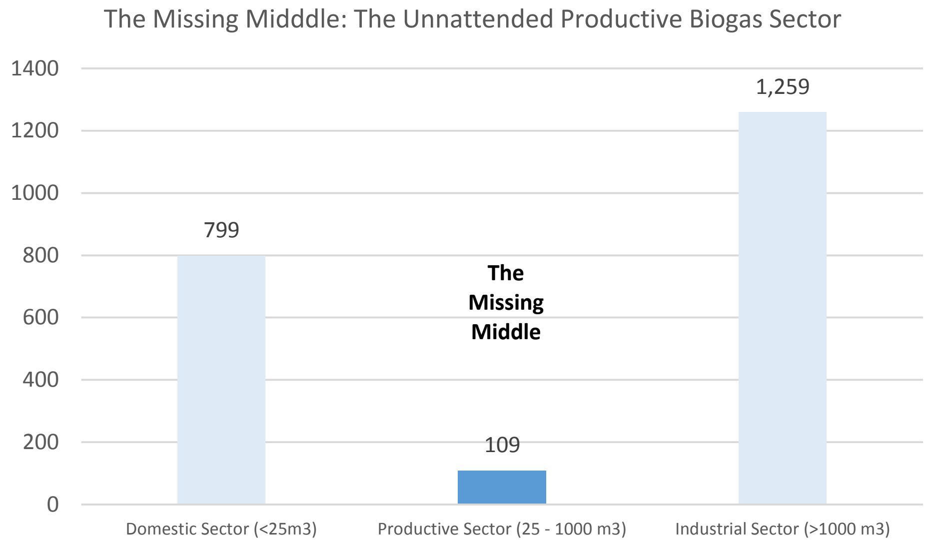

Figure 7: The missing middle: the productive biogas sector.

Biodigester specifications and typology

The lower end of Productive Sector digesters are tubular polyethylene modular continuous flow type biodigesters, essentially the same technology that predominate the Domestic Sector (see Domestic Sector Biodigester specifications and typology). Between 400 and 1,000 m3 systems are exclusively covered lagoon type (see Industrial Sector Biodigester specifications and typology).

Industrial Scale Biodigesters in Mexico

The Industrial Sector is defined for purposes of this study as systems that exceed 1,000 m^3 in volume. These systems are exclusively implemented in large agro-industrial livestock operations that have thousands or tens-of-thousands of animals across all phases of the growth cycle. The large majority of Industrial Sector biodigesters in Mexico were implemented through Clean Development Mechanism (CDM) projects (51%) and federal government programs run by SAGARPA-FIRCO (25%) while the remainder (24%) were implemented through a variety of private investments schemes (see Figure 8).

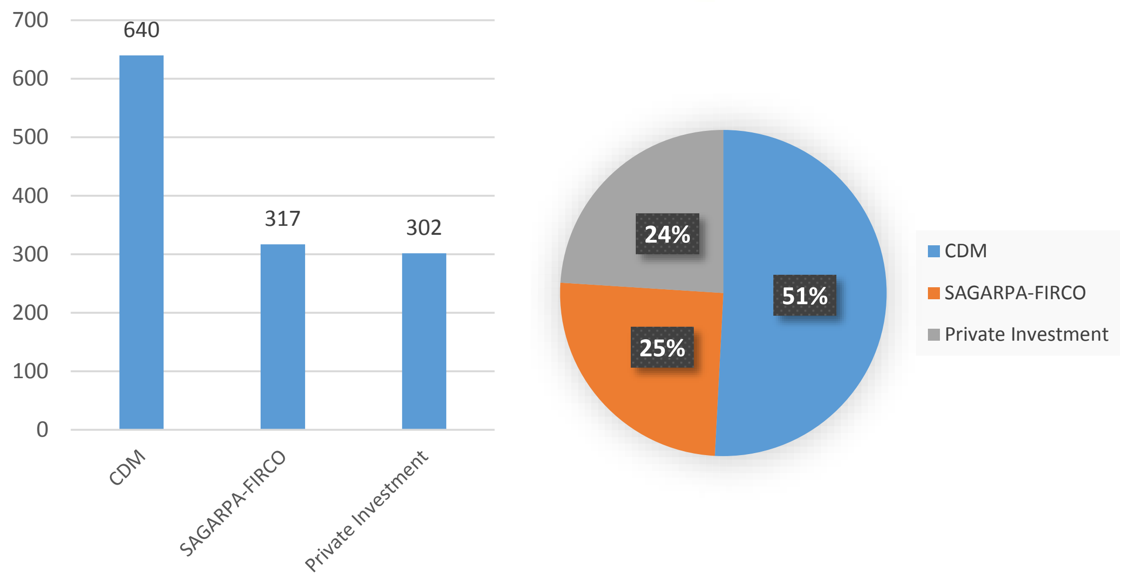

Figure 8: Industrial Sector biodigesters by funding mechanism in Mexico

World Bank CDM Projects

Since 2005, Industrial Sector anaerobic digesters in Mexico have been bolstered by Clean Development Mechanism (CDM) financing, a provision of the Kyoto Protocol that allows developed countries with greenhouse gas emission reduction targets to host projects that reduce emissions in developing countries. The Certified Emission Reductions (CERs) that result from these projects can be counted towards the reduction targets of the developed countries that sponsor the projects. Project sponsors can be governments or private companies that are obliged to make emission reductions, or consulting companies that develop the projects on behalf of clients that want to use these reductions for voluntary or compliance purposes. Currently, 51% (640 of 1259) of the Industrial Sector digesters in Mexico used CDM financing (see Figure 8).

SAGARPA – FIRCO

The Mexican Secretary of Agriculture and Rural Development (SAGARPA) and its financing trust the *Fidecomiso de Riesgo Compartido* (FIRCO) have been promoting AD technologies in the Industrial Sector since 2008 with government subsidies and competitive low interest loans. Over a 6 – year period these programs resulted in the installation of around 317 biodigesters in industrial scale hog and dairy farms throughout Mexico. The average cost of these systems was reported to be USD $170,000 with subsidies in the range of USD $50,000 -$70,000. Currently, 25% (640 of 1259) Industrial Sector digesters in Mexico used subsidies from SAGARPA-FIRCO (see Figure 8). SAGARPA-FIRCO have played the role of overseeing "quality assurance and control" within the Industrial Sector. SAGARPA-FIRCO published the *Technical Specifications for the Design and Construction of Biodigesters in Mexico* (2010) which has served to provide a basic framework of quality control.

Furthermore in 2014, SAGARPA-FIRCO in cooperation with ANCE[3] initiated a provider certification process for verifying the quality of Industrial Sector biodigester providers.[4]

Environmental Fabrics de Mexico

Environmental Fabrics International, a US based company and international leader in the commercialization of AD technology around the globe, established itself in Mexico as Environmental Fabrics de Mexico (EFM)[5] in 2004 in order to implement AD methane avoidance CDMs that were being promoted in the country. Due to their vast experience and technical capacity, EFM was contracted to install more than half of the CDM projects that were carried out in Mexico between 2005 and 2006. EFM acted as the primary subcontractor to implement the systems being managed by Ag Cert.[6]

Ag Cert

Ag Cert was the Project Design Document (PDD) consultant for majority of the CDM projects attempted in Mexico, and also has the highest failure rate, defined as projects that are listed on the UNFCCC webpage as being rejected, withdrawn, or validation stopped (Fennman, 2015).[7] Part of this failure can be attributed to Ag Cert's model, which was to take a large equity stake in projects and earn, in some cases, 90% of the resulting CERs in return for providing the capital and expertise to build the digester (Lokey 2009). However, when the price of carbon bottomed out and carbon credits became almost worthless at $6.57 USD in 2013 (Bloomberg Business), Ag Cert dissolved and found that it was no longer in its interest to maintain the existing digester projects.

Biodigester specifications and typology

The Industrial Sector biodigesters in Mexico have exclusively been "covered lagoon digesters." These systems represent a significant part of the Industrial Farm's infrastructure and occupy large areas within these farms. These systems should include the following components:

- Separation of Solids will depend on the manure management practices and the type and amount of solids in the manure
- Mixing station for proper monitoring and control of water-solids mix that enters into the digester
- Primary Anaerobic covered lagoon(s)
- Secondary and sometimes tertiary aerobic lagoon(s)
- Plumbing systems including separate systems for: Influents, effluents, biogas conduction and solids extraction
- Agitation systems for prevention of sedimentation, solids accumulation and clogging

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[3] www.ance.org.mx
[4] www.proyectodeenergiarenovable.com/empresas
[5] www.efdemexico.com
[6] AgCert was the Project Design Document (PDD) Consultant that managed the large majority of methane capture and destruction CDM project in Mexico. The PDD consultant is responsible for writing the initial document that establishes why the project should qualify for CERs, and often this consultant will shepherd the project through the tedious and long paperwork process to validate, register, verify, and eventually commercialize the Certified Emission Reductions (CERs).
[7] It should be noted that there are 10 other PDD consultants that each have one project in Mexico. Due to the low volume of projects for these PDD consultants, they are not shown in the chart above.

- Sample collection ducts for sampling influents and effluents of the system for temperature, pH and other physical and chemical parameters
- Biogas flow meters for measuring biogas production
- Hydrogen Sulfide filtration system
- Biogas burners

Additionally systems may include biogas pumps, motors or electric generators which can both autonomous (for use on site), or grid-tied through Net-metering contracts with National Electricity Commission.

The Current Situation; Survey and Evaluation of Existing Systems

The Survey and Evaluation of Existing Biodigesters in Mexico includes a technical and economic evaluation of the financial and technical performance as well as the impact and end-user perception of a large sample of the estimated 2,167 biodigesters that are catalogued in Mexico (as of September 2014). The evaluation focuses on identifying best practices, barriers, and useful case studies; all with the overall objective of providing concrete information of the role that biogas technology can have in reducing GHG emissions in Mexico and beyond.

Methodology

The survey is designed generate statistics by surveying a randomly selected sample of the overall population; this will allow us to make inferences to the entire biodigester population within an acceptable level of confidence based on the results of these samples.

Mexican National Biodigester Registry

The master database of biodigesters in Mexico can be considered as a valuable sub-product of this study that has potential uses beyond the scope of the study. This database is the result of a collaborative effort between various entities in Mexico including FIRCO-SAGARPA, The World Bank, Environmental Fabrics of Mexico and IRRI Mexico. The sum total of all non-overlapping systems in these databases is considered to be the global biodigester population within Mexico as of September 2014. As of this date, the combined total of all non-overlapping systems identified in these databases is 2167 (799 domestic, 109 productive, 1259 industrial).

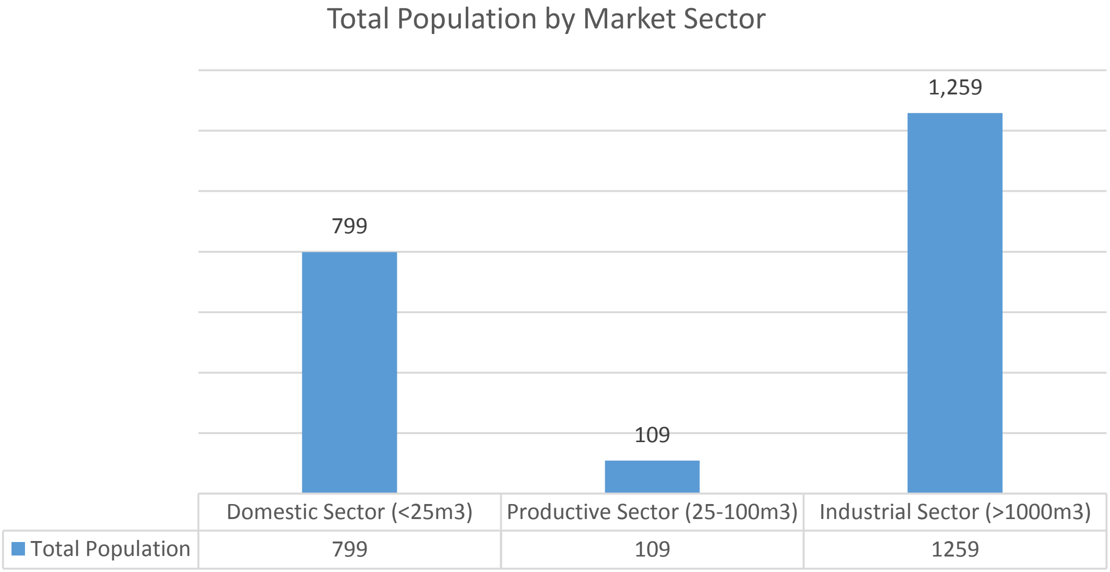


Figure 9: Total population in Mexico for each market sector.

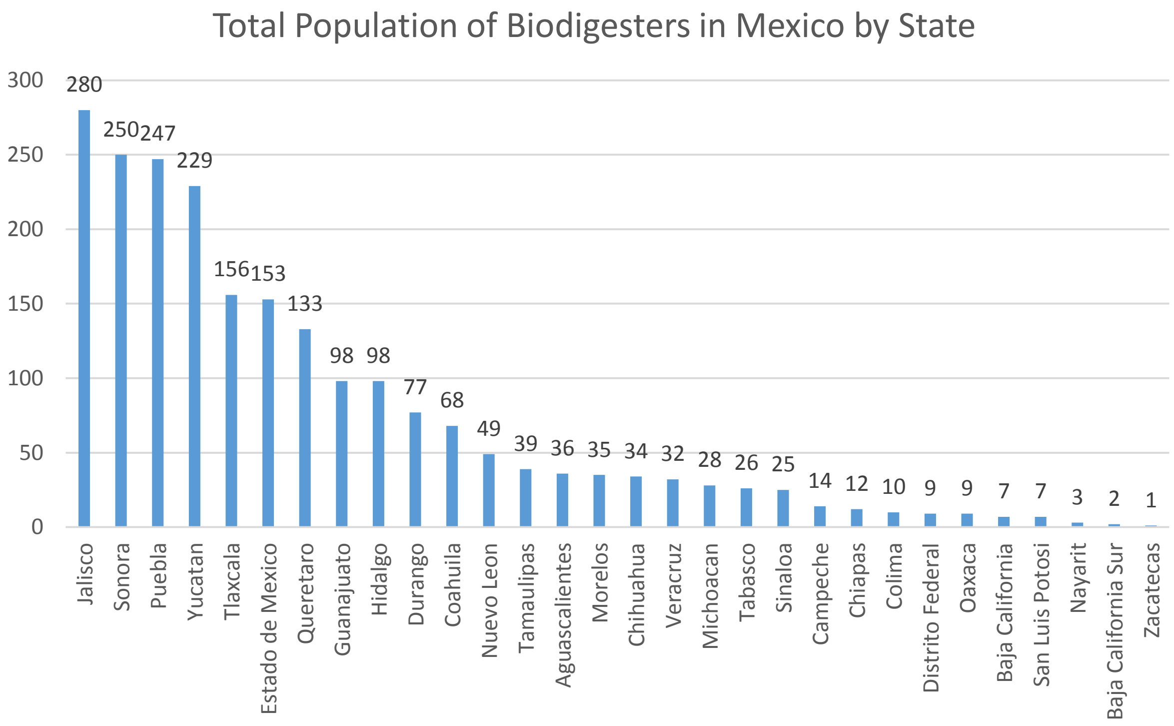


Figure 10: Total biodigester population in Mexico by state.

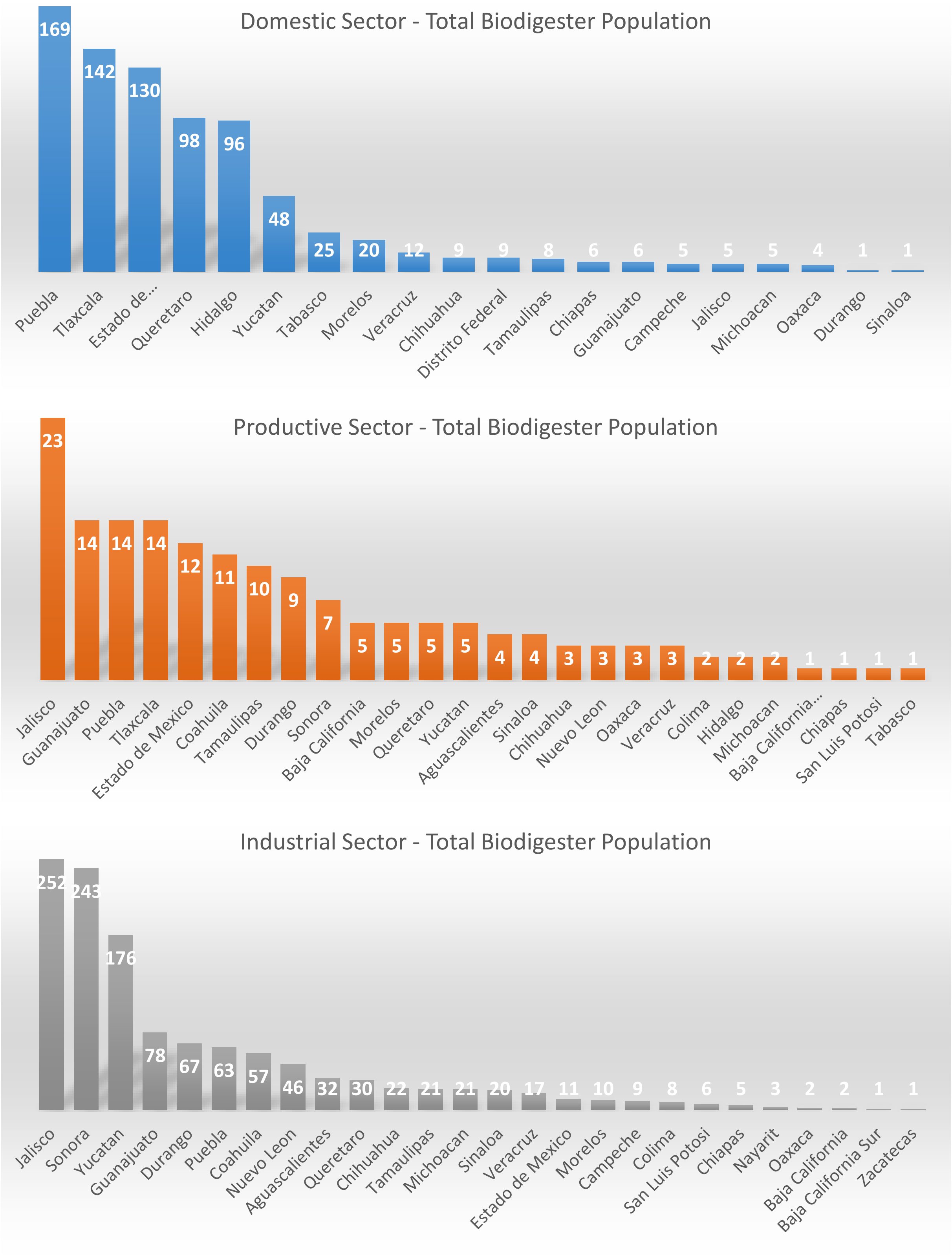


Figure 11: Distribution of biodigesters by State for each of the market sectors.

Sample Selection

The below equation gives us an estimated sample size that will be needed to survey in order to make assertions that are within our desired levels of confidence (90%). Choosing a P value of 0.8 may reduce the precision of statistical statements that are deduced from final data sets. This was a sacrifice made in order to maintain feasibility within budget and time constraints.

Equation 1: Equation for determining sample size base on population (N), desired levels of confidence (Z) and estimated final proportions (P)

$$n = \frac{N\, z^2_{\alpha/2}\, P(1-P)}{(N-1)e^2 + z^2_{\alpha/2} P(1-P)}$$

By choosing a P value of 0.8 and choosing a random sample within each distinct group we are given representative sample sizes for each market sector (Domestic, n = 142; Productive, n = 84, Industrial, n = 152).

Table 1: Target sample size for each market sector.

		< 20 m^3	20 – 1,000 m^3	> 1,000 m^3	Totals
	Total population-->	799	109	1,259	2,167
# of Surveys at P=0.8 (target sample size)	0.8	142	67	152	378

Assumptions

Several assumptions were used in the database sorting process including:

1. Market sectors are defined in this study through the proxy of system liquid phase volume capacity.
2. In the cases where the databases lacked the parameter of total animal population was used to estimate system volume in order to place systems in their respective market sectors (domestic, productive, industrial).

Selection Criteria

In order to increase the efficiency of the field survey implementation phase of the study several sample selection criteria were used to filter the sample by density of geographical system distribution at the state level. These criteria were applied to each market sector separately. The selection criteria were:

1. Systems were eliminated from the sample in cases where they are located in states in which the entire system population is "five or less" biodigesters (Domestic: 3 systems in 2 states, Productive: 27 systems in 14 states, Industrial: 2 systems in 2 states).
2. In the cases where the random sample selected "three or less" systems in a given state, those systems were replaced with a random selection from another state with a sample size of 4 or more (Domestic: 11 systems in 7 states, Productive: 1 systems in 1 states, Industrial: 10 systems in 6 states).

Final Sample Selection

Following the application of the above selection criteria we were given a final sample distribution by market sector and geographical location.

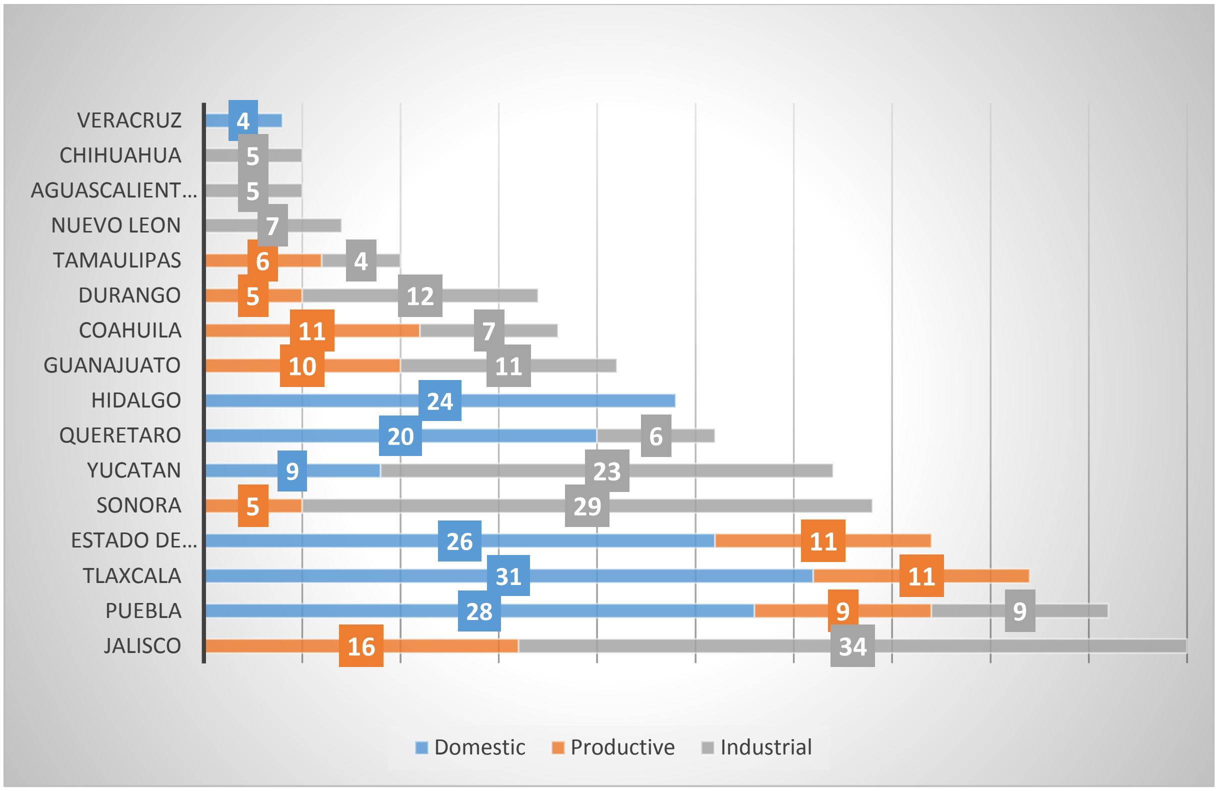
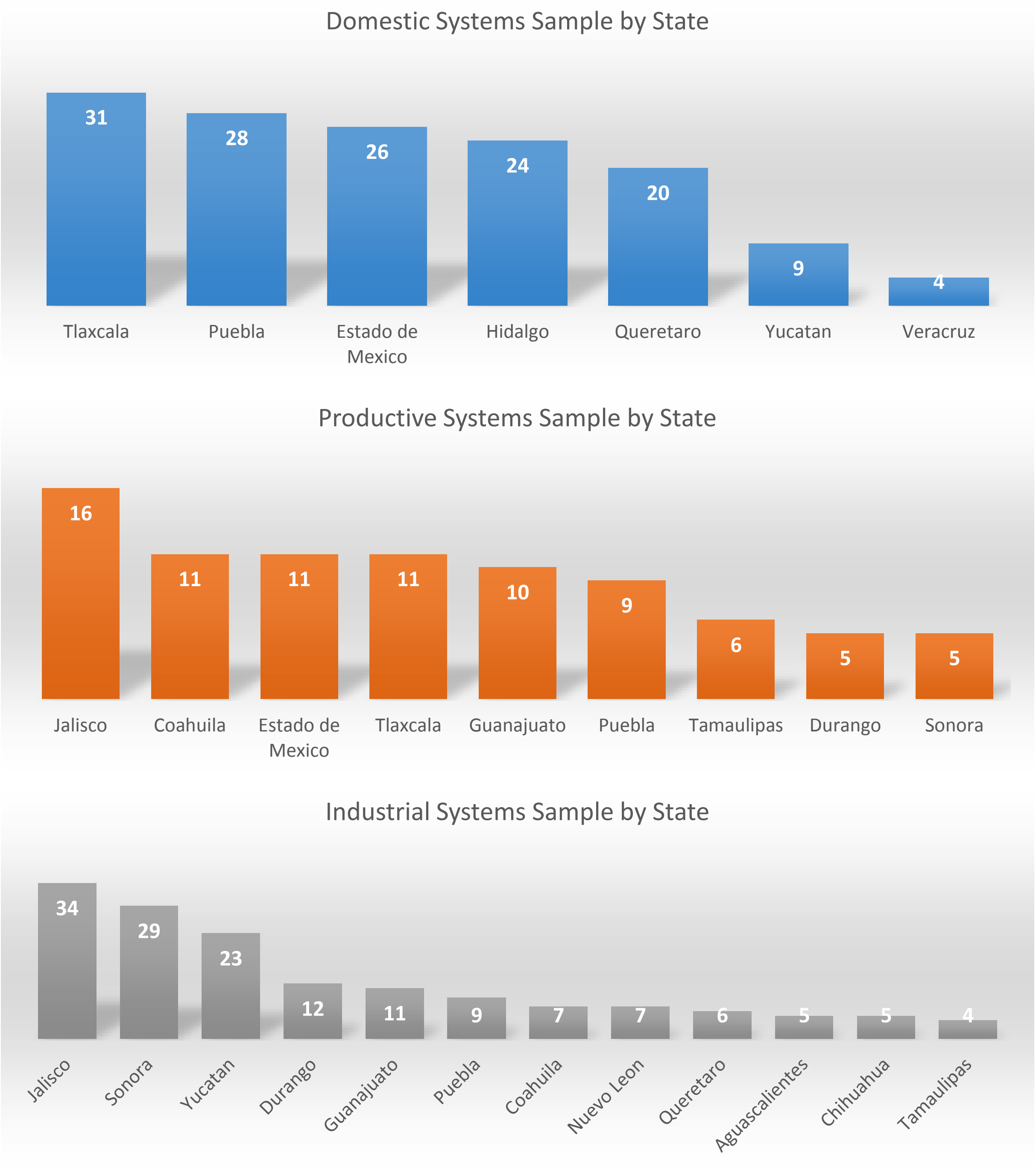


Figure 12: Statistically representative sample by market sector and state.



Domestic Systems Sample by State

Productive Systems Sample by State

Industrial Systems Sample by State

Figure 13: Sample distribution by state for all market sectors.

Actual Sample Implemented

Having defined the sample target for each sector, the surveys were launched on February 7, 2015, in 19 states within the Mexican territory simultaneously. Surveys were conducted in each state by teams of trained technicians with background in anaerobic biodigester technology over a nine-week period ending on April 15, 2015. In the case of domestic systems, 140 surveys were conducted from a total population of 799 registered biodigesters. In the Productive Sector 44 surveys were conducted from a total population of 109, while 108 Industrial Sector surveys were completed from a total population of 1,259 (Figure 14).[8]

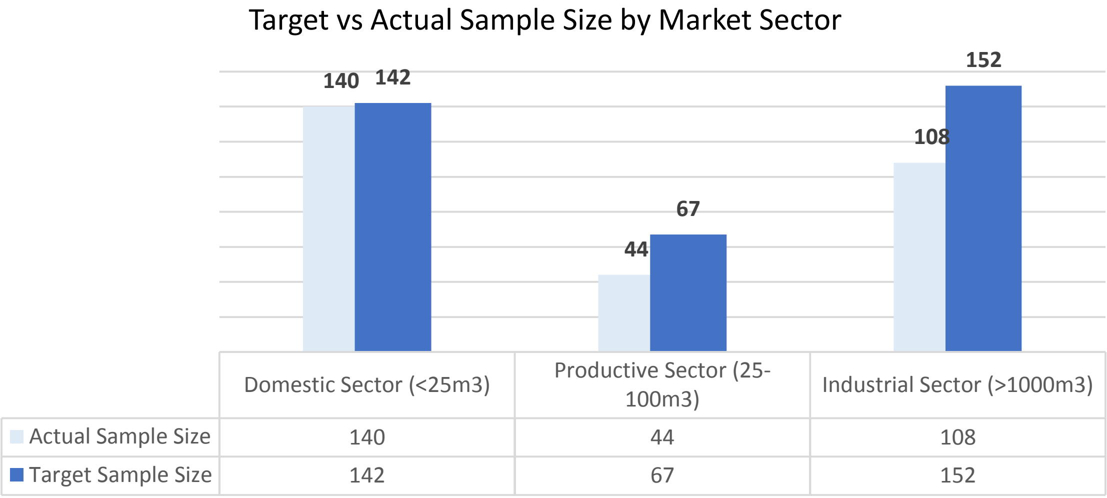


Figure 14: Target vs Actual Sample Size by Market Sector

Percentage of Population Sampled by Market Sector

In total survey enumerators were able to visit 18% of the total population of domestic biodigesters, 40% of the productive systems and 9% of the industrial systems, while the targets were 18%, 61% and 12% respectively.

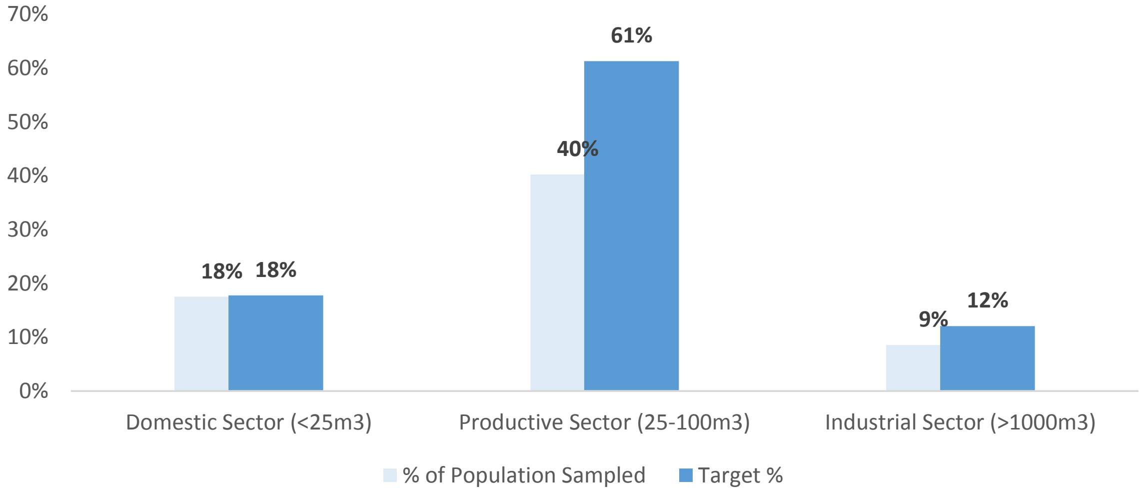


Figure 15: Population sampled from compared to the market target.

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[8] In the states of Nuevo Leon (43%) and Tamaulipas (75%) many of the systems that were selected in the sample were abandoned because the farm closed due to the owner being extorted by a regional drug cartel.

Greenhouse Gas Reduction Calculations

The GHG reductions from anaerobic digestion systems to capture and destroy methane at animal production units is a well understood process, defined technically in the original United Nations Framework Convention on Climate Change (UNFCCC) Clean Development Mechanism (CDM) in 2003. The baseline for GHG emissions reductions at farms is based on two key mechanisms. First, animal waste, when stored in lagoons, pits, or large piles, creates anaerobic zones that begin to produce methane gas. Methane gas has 21 times the climate change forcing potential of CO2, and therefore these emissions create a significant source of GHG. Burning methane converts it back to CO2, and therefore reduces the additional heat retention potential. Second, farms and farm households have baseline GHG emissions from their energy use when they use non-sustainable biomass fuels or fossil fuels.

As an intervention, AD systems capture the methane gas released from the animal manure. The methane is then used in a biogas appliance—stove, boiler, or motor—where it is destroyed through combustion, creating a clean energy source. This energy source, in-turn, displaces biomass of fossil fuels, further reducing emissions. The methodologies to measure and calculate those reductions are based on the scientific understanding on the chemical and biological breakdown of animal and other organic wastes under anaerobic conditions and the rate at which biomass and fossil fuels produce emissions.[9]

There are a number of different schemes for accounting for and commercializing emissions reduction (ERs). This can include voluntary (VERs) or certified (CERs) mechanisms. However, the definitive methodology for how those ERs are calculated is the UNFCCC methodology. The calculation of ERs is broken into a few different methodologies, which in sum allow the full ER to be calculated.

This project utilized the best practices, calculations and default values from these methodologies to calculate the estimated GHG impacts of the projects sampled. The calculations are not done to propose a specific, commercially viable ER; this would require a number of administrative steps and more precise and specific evaluation of each farm. However, using conservative values, and taking the population of farms in aggregate, we are able to generate a strong estimate as to the true ERs from the farms sample, and how that may relate to the ERs from all of the AD systems in Mexico. These estimates also provide a good estimate as to the GHG ERs for future AD system development.

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[9] The liquid effluent from AD systems can be used as a soil amendment and fertilizer that has the potential to displace significant amounts of nitrogen-based fertilizers. These fertilizer release CO2 in their production and transport, and application. This was not applied for this study.

Table 2: Methodological basis for calculations of Greenhouse Gas emission reductions

Methodology or Reference[10]	**Description**
2006 IPCC Guidelines for National Greenhouse Gas Inventories: CHAPTER 10 EMISSIONS FROM LIVESTOCK AND MANURE MANAGEMENT	Provides the key default and calculation factors for all reductions methodologies related to manure management
AMS-III.D Small-scale Methodology Methane recovery in animal manure management systems	This provides the specifics for calculating and measuring the reduction of methane emissions from animal manure
III.R. Methane recovery in agricultural activities at household/small farm level	This provides for a consolidated methodology to measure groups of smaller farms, reducing measurement requirements.
AMS-I.A. Electricity generation by the user	This provides the guidelines for calculating the emissions reduction when the biogas is used to reduce the use of fossil fuels or grid-tied electricity.
AMS-I.C Small-scale Methodology Thermal energy production with or without electricity	This provides guidelines for the use of biogas for thermal energy production to displace fossil fuels and biomass.
AMS-III.A Small-scale Methodology Offsetting of synthetic nitrogen fertilizers by inoculant application in legumes-grass rotations on acidic soils on existing cropland	This provides the baseline for calculating the emissions reductions from displacing nitrogen fertilizers with biol from AD systems.

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[10] Source: AMS-III.D Small-scale Methodology

Equation 2: Equation for estimating methane recovery in methane capture and manure management systems

$$BE_y = GWP_{CH4} \times D_{CH4} \times UF_b \times \sum_{j,LT} MCF_j \times B_{0,LT} \times N_{LT,y} \times VS_{LT,y} \times MS\%_{Bl,j} \qquad \text{Equation (1)}$$

Where:

BE_y = Baseline emissions in year *y* (t CO_2e)

GWP_{CH4} = Global Warming Potential (GWP) of CH_4 applicable to the crediting period (t CO_2e/t CH_4)

D_{CH4} = CH_4 density (0.00067 t/m^3 at room temperature (20 ºC) and 1 atm pressure)

LT = Index for all types of livestock

j = Index for animal manure management system

MCF_j = Annual methane conversion factor (*MCF*) for the baseline animal manure management system *j*

$B_{0,LT}$ = Maximum methane producing potential of the volatile solid generated for animal type *LT* (m^3 CH_4/kg dm)

$N_{LT,y}$ = Annual average number of animals of type *LT* in year *y* (numbers)

$VS_{LT,y}$ = Volatile solids production/excretion per animal of ~~for~~ livestock *LT* in year *y* (on a dry matter weight basis, kg dm/animal/year

$MS\%_{Bl,j}$ = Fraction of manure handled in baseline animal manure management system *j*

UF_b = Model correction factor to account for model uncertainties (0.94)[1]

Research Instruments

A sector specific survey was created for each of the market sectors in order to capture the unique characteristics of each sector. These surveys focus on obtaining technical and financial data from the biodigesters and electricity generation systems (when applicable). The surveys also capture the manure management practice, fertilizer use and energy profiles in order to stablish baseline scenarios. In addition data about biogas and effluent uses is gathered in order to quantify the financial and climate impact of these systems.

Domestic Sector Survey Results

Introduction

The Domestic Sector is characterized by backyard farms in rural communities that have been assisted with a biodigester through poverty alleviation programs managed by the government or private foundations. This section will describe the type and size of these farms, and the impact that the biodigester has made in these households. The financial benefits are derived from the use of biogas as an energy source that displaces LPG and woodfuel consumption. In addition, some beneficiaries see financial savings from the use of the biodigester effluent as fertilizer. The climate impact of these systems will be analyzed from two sources: the manure management practices and the displacement of fossil fuel consumption.

Image 5: Beneficiaries of domestic scale biodigester funded by the Kellogg Foundation in Yucatan

Domestic Sector Characteristics

The Domestic Sector is composed of backyard farms located within the property of the user's home. These sites are located in rural communities and usually cover an area of one or two hectares where they grow crops to complement their animal operations. As shown in Figure 16, 61% of the digesters in this sector have the two smallest systems available on the market: the 4 and 6 m^3 digesters. There was only one 14 m^3 system and two 16 m^3 systems in the surveyed sample. For this reason, any results drawn for smaller systems will be more accurate than the results drawn for larger systems.

Most of the farms have less than 50 animals: 40% have less than 10 animals, and only 10% have more than 50 animals. The most common cattle types in this sector are bovine, porcine and ovine with 39%, 22% and 19% of the Domestic Sector respectively. Less frequently farms have chickens, goats and rabbits. The majority have a single type of cattle, and 40% of the farms have a mixture of cattle types. Most of the programs that have sponsored biodigesters in the Domestic Sector are located in Central Mexico, and as a result, 78% of the systems are located in temperate climates, with only 13% and 9% in hot and cold climates respectively.

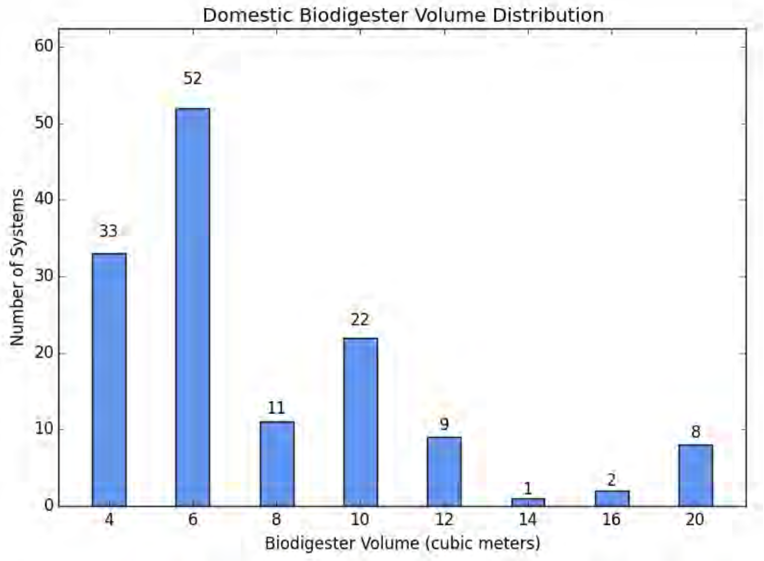

Figure 16: Biodigester volume distribution

The biodigesters in the Domestic Sector are performing very well in the country as 125 out of 140 (89%) are "working well" or "working well with minor issues" (see Figure 17). Only 1% of the systems in the sector are not working is because of technical issues while 10% are not working due to lack of use or abandonment.

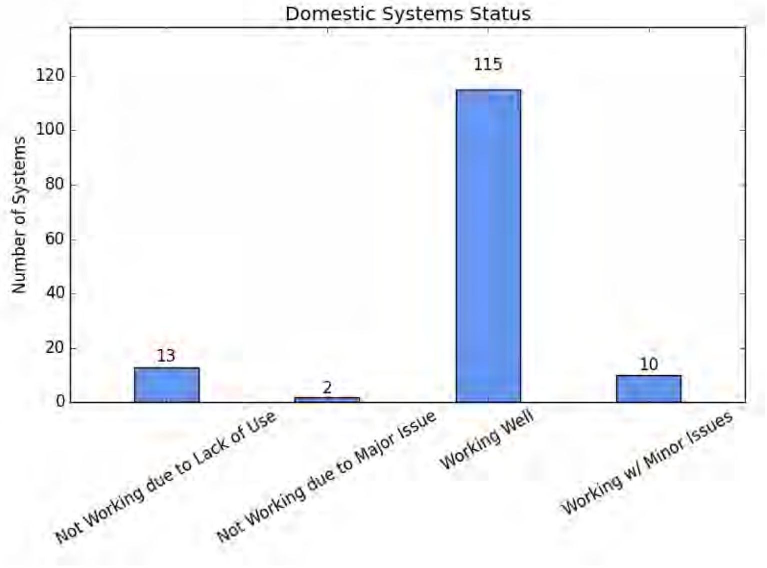

Figure 17: Biodigester systems status

Image 6: Cows and sheep are typical backyard farm animals in Central Mexico

Financing Mechanisms

Although the results show (see Financial Benefits section) that the domestic scale biodigesters generate significant financial benefits for the beneficiary's household economy, the total cost of these systems is prohibitively expensive for most families in this sector. Therefore, these systems are usually implemented through government assistance programs targeted towards poverty reduction, foundations and social initiatives. The financial mechanisms used to support these projects include a wide range of groups including the following (see Domestic Sector Background section):

SEFOA (PESA)	PESA	ENDESU
KIVA	SEDESOL	AIPIR
SEMARNAT (PESA)	SEDEA	CDI
SEDAGRO (PESA	INAES	Produce Foundation
	W.K. Kellogg Foundation	

It should be noted that SEFOA, SEMARNAT and SEDAGRO are state level implementing partners of PESA Mexico which when added together represent 52% of the domestic biodigesters in the country (Figure 18). Unknown (33%), Kiva (29%), and W.K. Kellogg Foundation (11%) funded projects have the highest rate of failure.

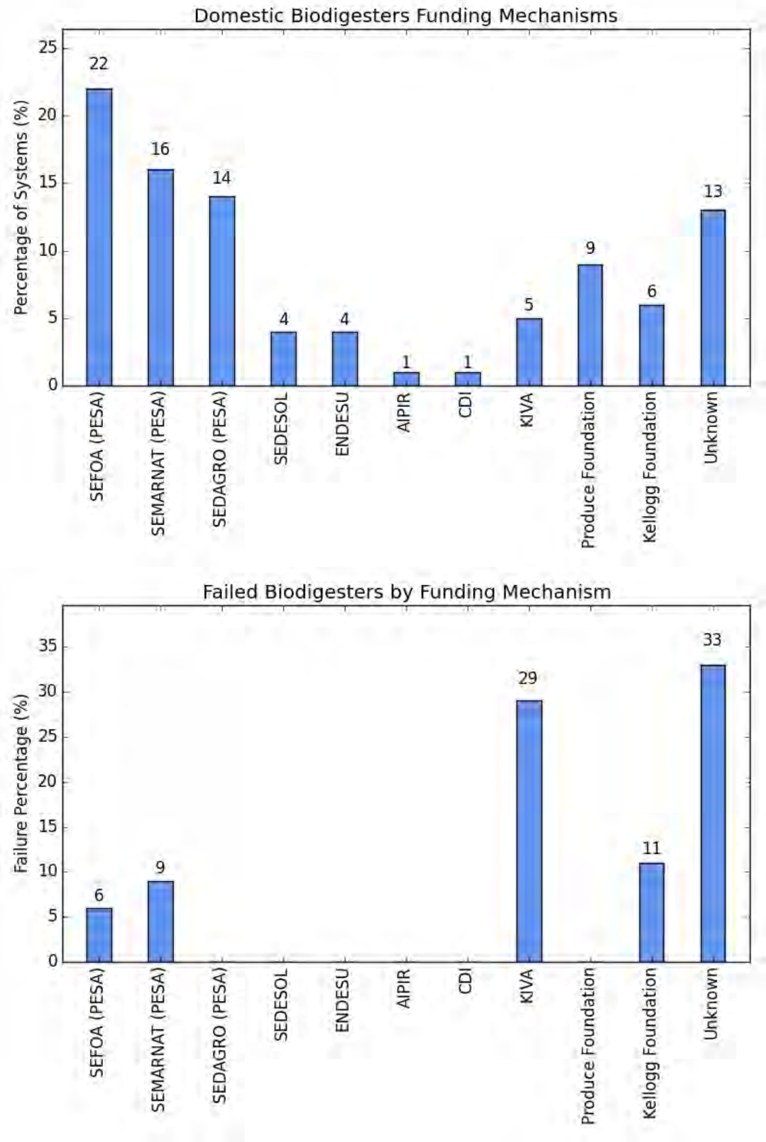

Figure 18: Top: Proportion of domestic biodigester by funding mechanisms. Bottom: Failed system rate by funding mechanism.

Manure Management

The installation of the biodigester in this sector generates significant improvements in the manure management practices of the typical beneficiary. In the baseline scenario (before the installation of the digester) all of the manure was stored in piles on the ground (36% on-site and 64% off-site) in order for the manure to be spread over fields during the growing season. These off-site fields belong to the farmer but are geographically separated from the animal operations.

Image 7: Bovine manure piled up in a Tlaxcala dairy farm

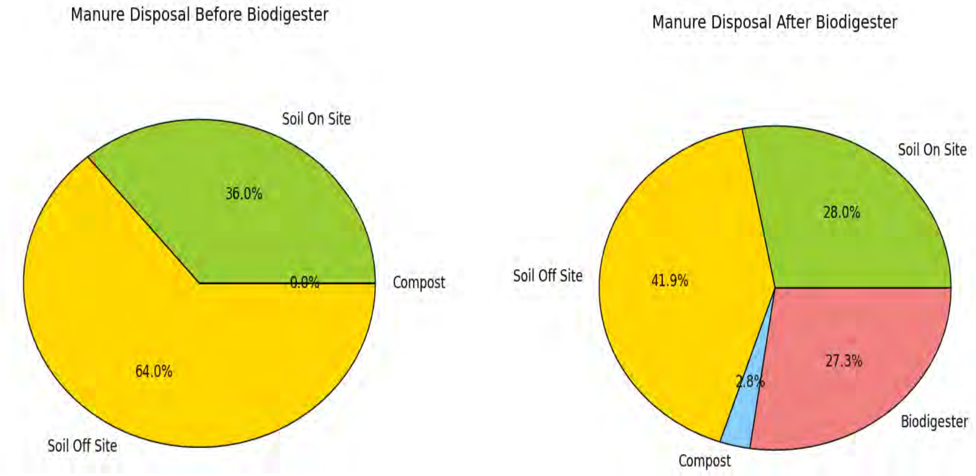

Figure 19: Manure disposal before and after the installation of the biodigester

On average, 24% of the manure from all of the farms in the sector goes into the digester. Almost half of the farms (49%) treat 0-20% of their manure in the digester and 26% of the farms treat 20-50% of their manure in the digester (Figure 20). Only 25% of the sector sends 50% or more of their manure to the digester. Farmers land apply, ship offsite, and to a lesser degree compost the remaining manure that does not go to the digester. The digesters are supported by governmental programs and often are not big enough to accommodate the manure from all of the animals onsite.

More than half of the users only feed bovine manure into the digester, but almost 40% of users combine different types of manure into the digester.

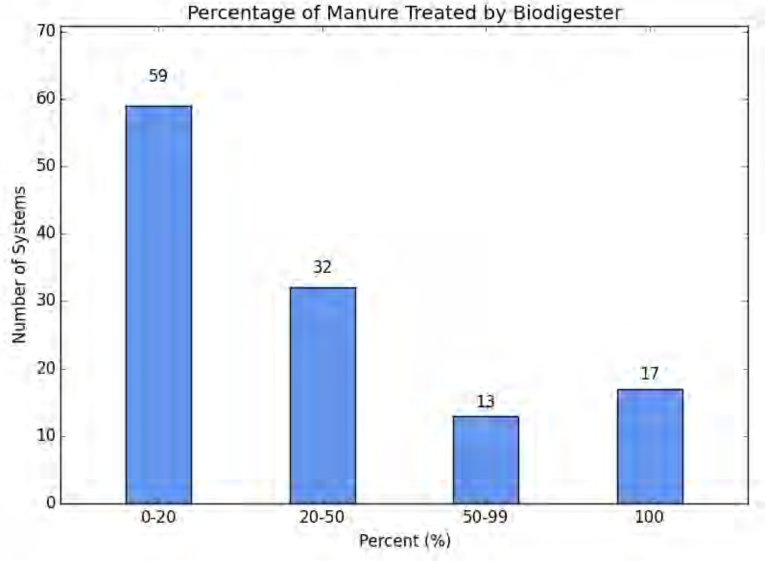

Figure 20: Percentage of manure treated by biodigesters

Farmers do not always follow the directions for proper digester management. The ratio of water to manure should be three to one for bovine manure and five to one for other types of manure such as porcine, ovine and caprine. The survey results show that many farms with bovine manure are not using enough water in the digester which could result in the undertreating of manures and / or system failure. The availability of year-round water does not seem to influence the success of a system; 2% of the users reported not having water available all year, but their digesters are still working well.

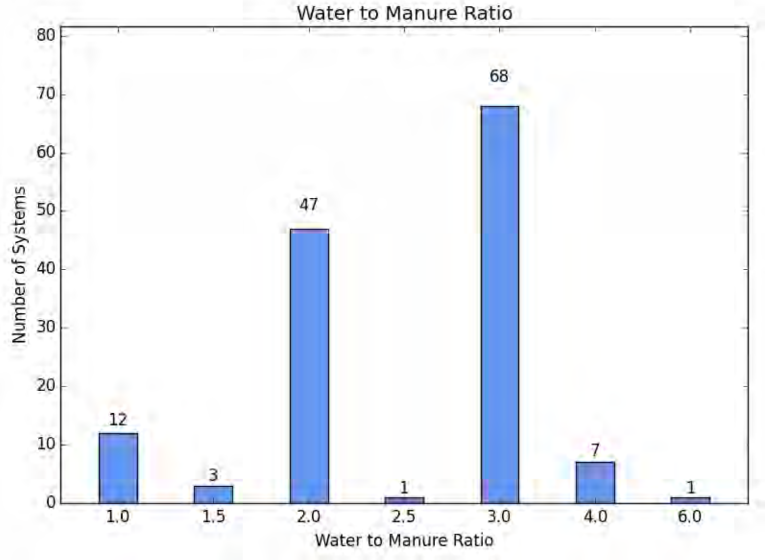

Figure 21: Water to manure ratio used for feeding biodigesters

The amount of manure that a biodigester can treat depends primarily on the volume of the digester. As shown in Figure 22, users with 4 m^3 systems treat on average 10 kg of manure a day while users of 12 m^3 systems treat on average 50 kg of manure a day (well below digester capacity). The variability of manure treated by a digester varies considerably from site to site. For example, some users with a 20 m^3 system treat less than 50 kg per day, and others more than 100 kg. Factors such as manure type, water to manure ratio and site climate may affect the amount of manure users decide to put in the digester. As we saw in Figure 19, the manure that is now being treated by the digester was stored on the ground before the installation of the biodigester. When the manure is piled it tends to produce methane gas that escapes into the atmosphere. With the installation of the biodigester this methane is now captured and burned. The reduction in GHG emissions from the manure treatment depends on the manure type and the site climate. For this reason there is a great deal of variability in the GHG emissions reduction for each site with the same digester size. On average, a 10 m^3 system reduces the annual GHG emissions by 1.93 MT of CO2e, but some sites under the same digester size have emission reductions of less than 0.50 MT of CO2e, and other sites have emission over 10 MT of CO2e.

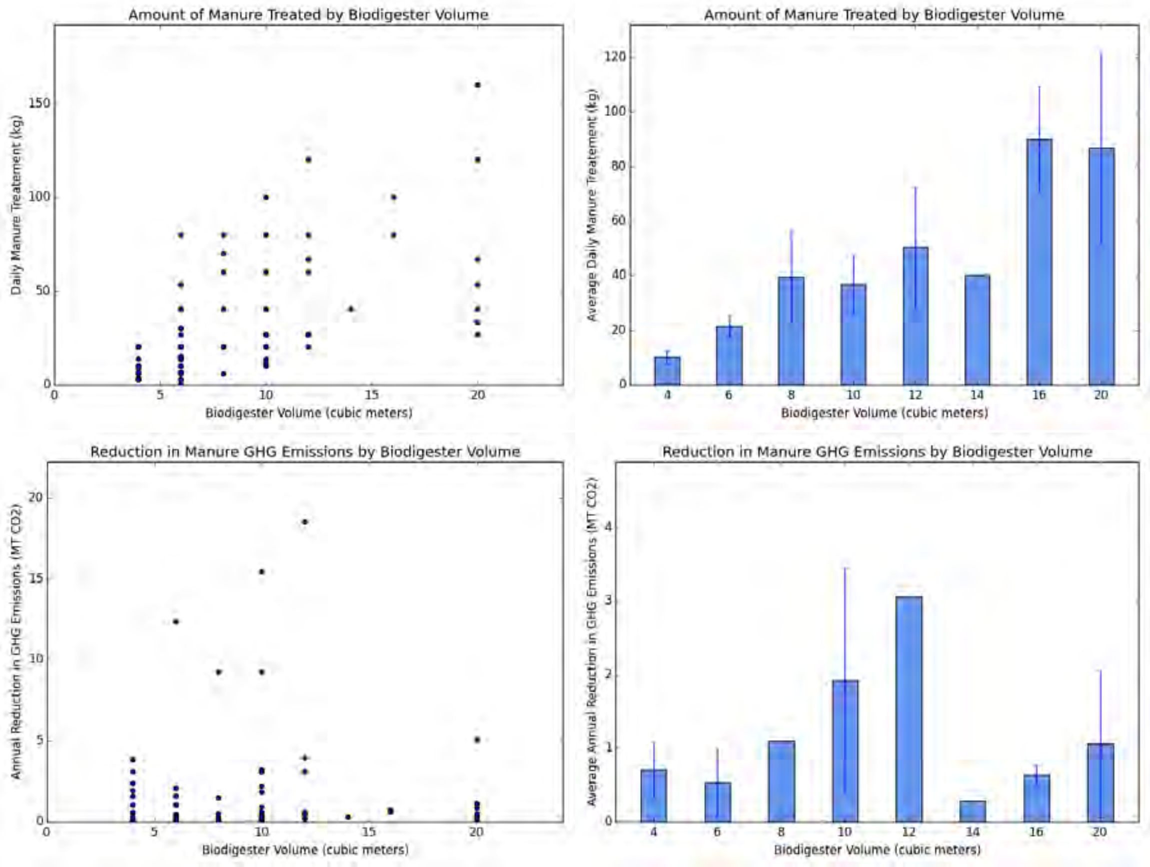

Figure 22: Top: Daily amount of manure treated by biodigesters. Bottom: Annual reduction in GHG emissions (error bars represent 95% CI)

Financial and Climate Impacts of Biogas Production

Users in the Domestic Sector make use of biogas for household cooking and water heating. In the baseline scenario the primary fuel types utilized for heating water and cooking are LPG and woodfuel. Therefore the use of biogas tends to displace these fuels translating into financial and or time savings for the user and greenhouse gas emissions reductions (GHG ERs). Depending on the system size and energy needs, some users are able to completely suppress their LPG or wood usage. The following section will analyze the financial and climate impacts that the displacement of fossil fuel consumption by biogas has for different digester sizes.

In the Domestic Sector, biogas is utilized exclusively for two main purposes: household cooking (70%) and heating water (70%) for bathing. Moreover, 2% of the users heat the water for cleaning purposes. In most cases cooking is the only use given to biogas, and in fewer cases biogas is used for both cooking and water heating. The amount of biogas produced increases as the volume of the digester increases, as one might expect, in a linear relationship (see Figure 23).

Image 8: The indicative blue flame of methane combustion in domestic biodigester application in Yucatan

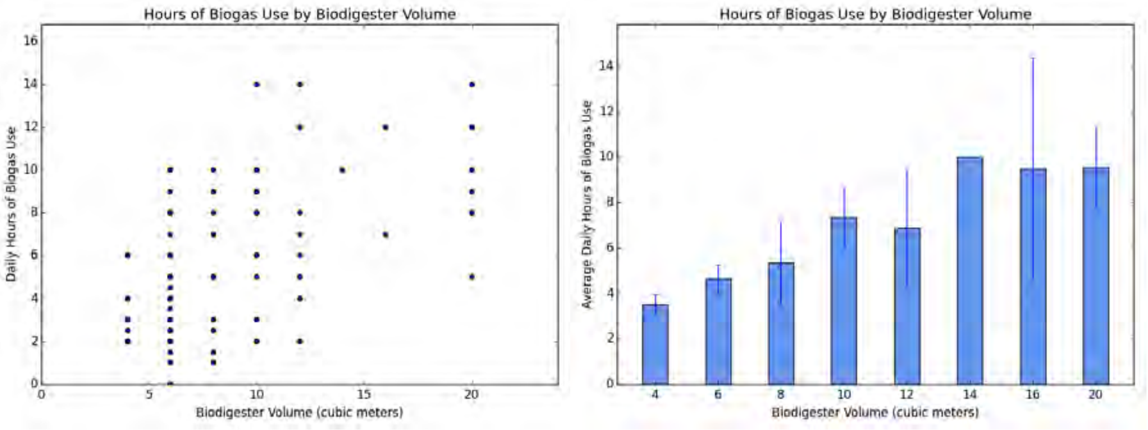

Figure 23: Daily hours of use of biogas by biodigester volume emissions (error bars represent 95% CI)

LPG

The main source of energy for cooking and water heating in the Domestic Sector is LPG. Figure 24 shows that the reduction in LPG consumption increases with digester volume. On average, a 4 m^3 system provides a monthly reduction of 6 kg of LPG, whereas a 10 m^3 system provides a monthly reduction of 23 kg of LPG. The results in Figure 4 do not show that the displacement of LPG consumption increases with the bigger systems (12-20 m^3). This may be due to the limited amount of systems surveyed in that volume range, but if more data was available, it would be expected to see that displaced LPG consumption increases with digester volume. In terms of financial savings, a 4 m^3 system provides monthly savings of \$72 MXN, whereas a 10 m^3 system provides monthly savings of \$300 MXN from displaced LPG consumption.

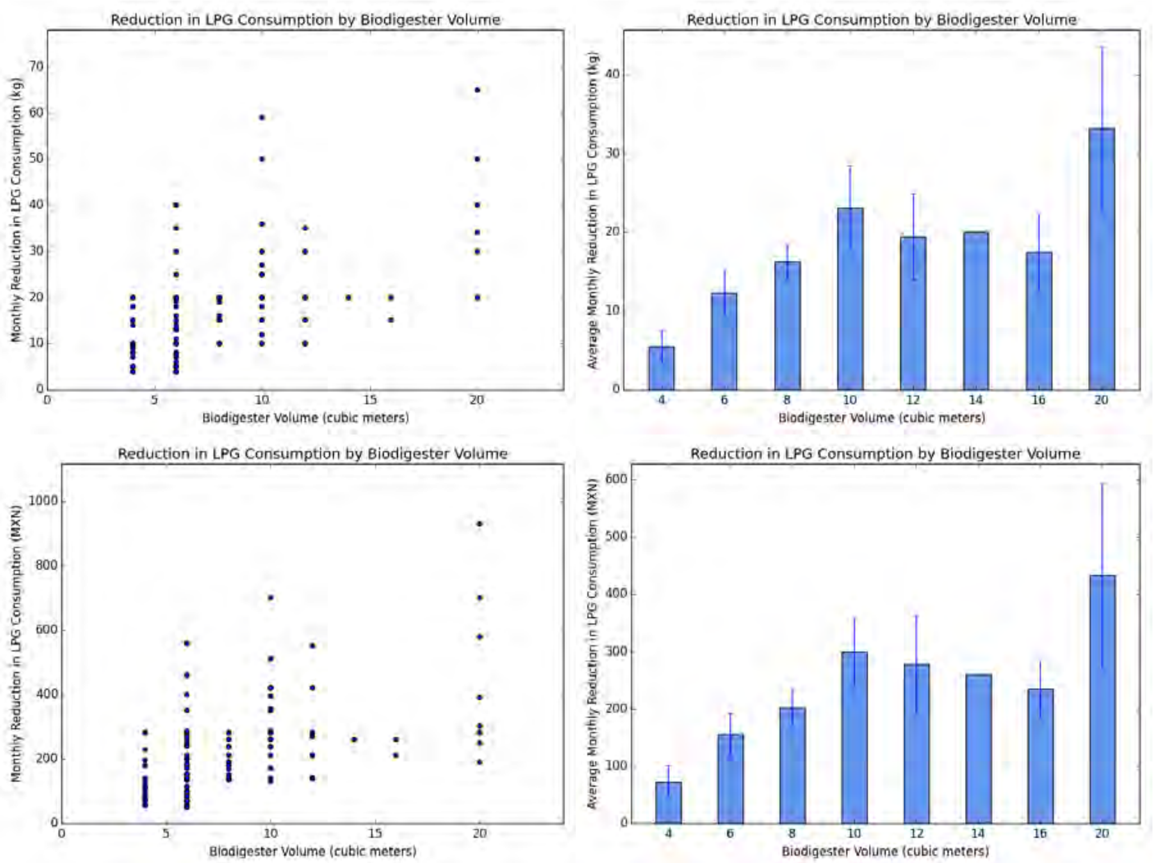

Figure 24: Top: Monthly reduction in LPG consumption. Bottom: Monthly savings in LPG consumption emissions (error bars represent 95% CI)

For each system volume, the annual GHG ERs from LPG was calculated in MT of CO2e. Analogous to the displacement of LPG consumption, the GHG ERs from LPG increases with volume size (Figure 25). On average, a 4 m^3 system provides an annual reduction of 0.01 MT of CO2e, whereas a 10 m^3 system provides an annual reduction of 0.04 MT of CO2e, through displaced LPG consumption.

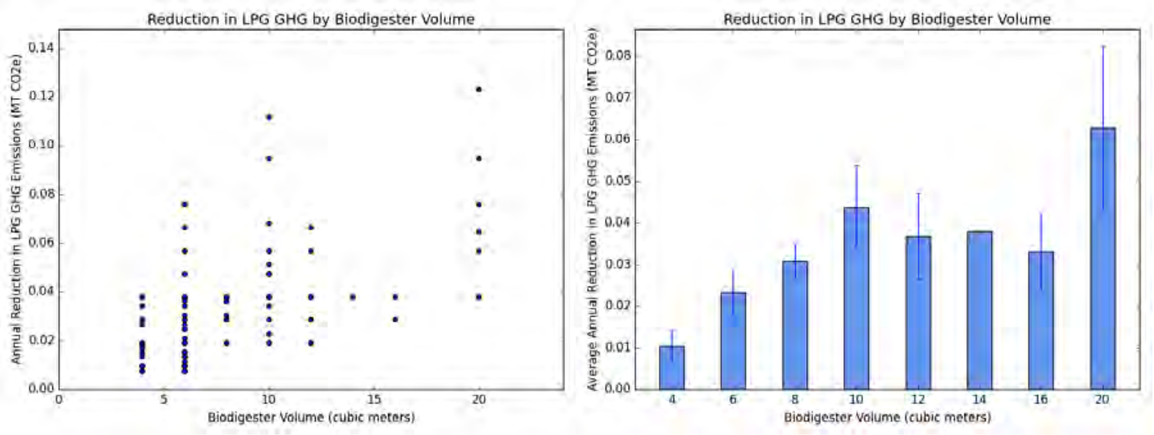

Figure 25: Reduction in LPG GHG emissions by biodigester volume emissions (error bars represent 95% CI)

Woodfuel

Users who own smaller systems tend to have fewer animals and lower income. Farmers under these financial circumstances heat and cook with woodfuel, which costs less and is more accessible than LPG. Users with bigger systems tend to have more animals and higher income and as a result can afford to use LPG. In Figure 26 we can see that the greatest reduction in woodfuel consumption was generated by users with smaller digesters (4-6 m^3), whereas farmers with larger digesters did not save more on woodfuel because these farmers do not use woodfuel in the first place. The price of wood is highly variable from region to region, and for this reason the financial savings from wood does not correlate well with the amount of displaced wood. Furthermore, in many cases wood is collected from the surroundings of the user's home, and for these cases the benefit is in the form of more free time available to dedicate towards other activities besides collecting wood.

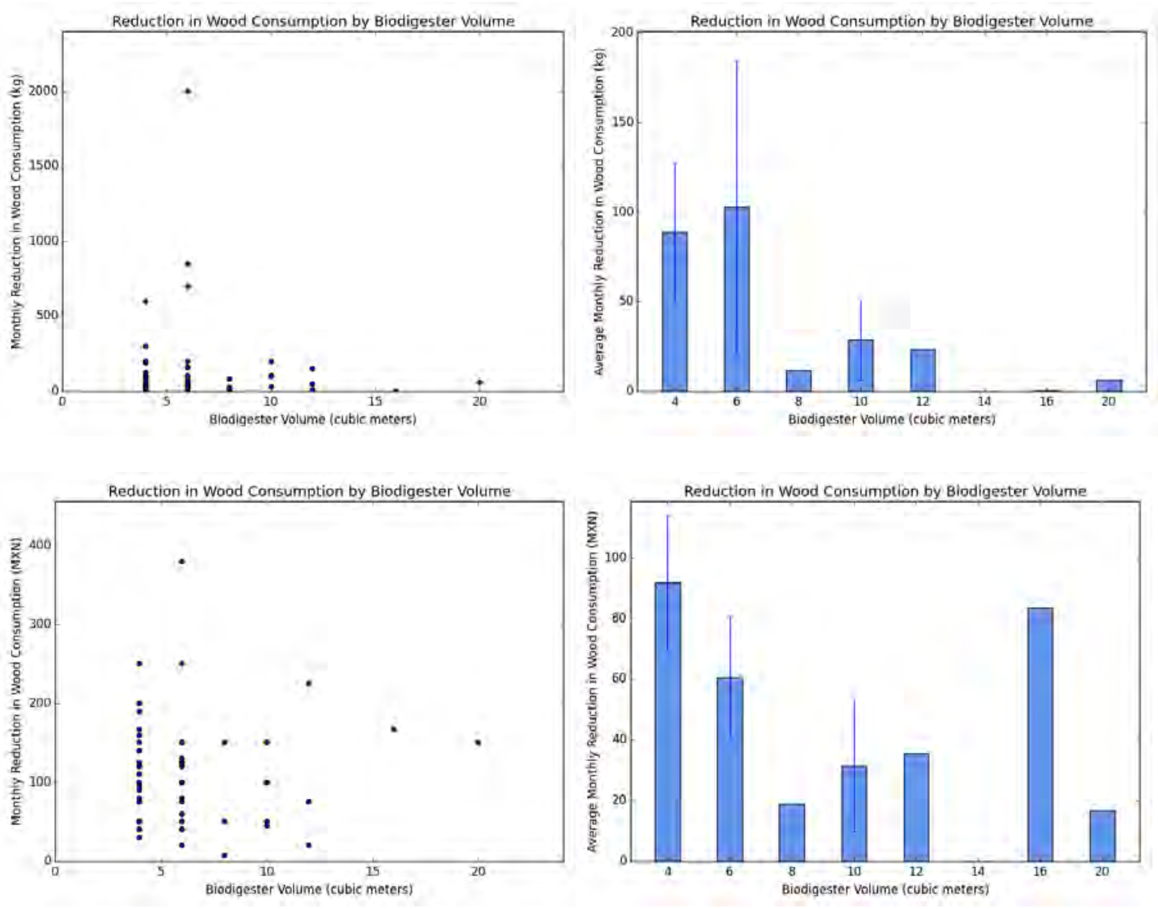

Figure 26: Top: Monthly reduction in wood consumption. Bottom: Monthly savings in wood consumption (error bars represent 95% CI)

The GHG ERs derived from the displacement of woodfuel consumption are the result of unsustainably-harvested woodfuel. In this study, it was assumed that 30% of the woodfuel used by these communities is not regenerated. Based on this assumption, Figure 27 shows that the GHG impact of woodfuel is much larger than LPG. On average, a 4 m^3 system provides an annual reduction of 0.65 MT of CO2e, whereas a 6 m^3 system provides an annual reduction of 0.75 MT of CO2e.

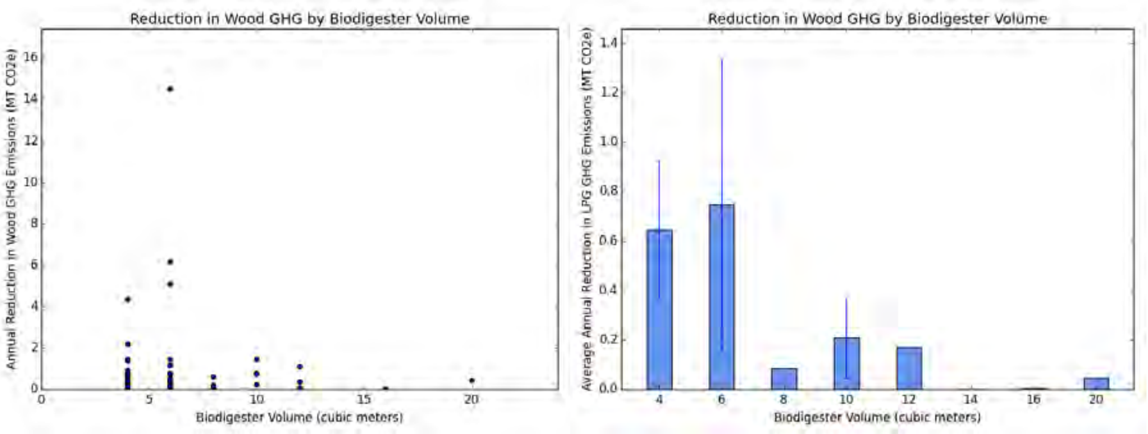

Figure 27: Reduction in wood GHG emissions by biodigester volume (error bars represent 95% CI)

Summary - Financial and Climate Impacts of Biogas Production

The displacement of LPG and woodfuel consumption generated by the use of biogas can result in significant financial savings and GHG ERs. The financial impact depends mostly on the quantity and cost of fuel displaced. The biodigester size determines the amount of biogas available, and the more biogas available, the more fossil fuel is displaced, hence higher savings. On the other hand, the level of impact in GHG ERs depends primarily on the type of fuel displaced. This is because woodfuel has a much higher GHG emission potential than LPG. The financial savings and GHG ERs from the displacement of fossil fuels by the use of biogas are shown in Figure 28.

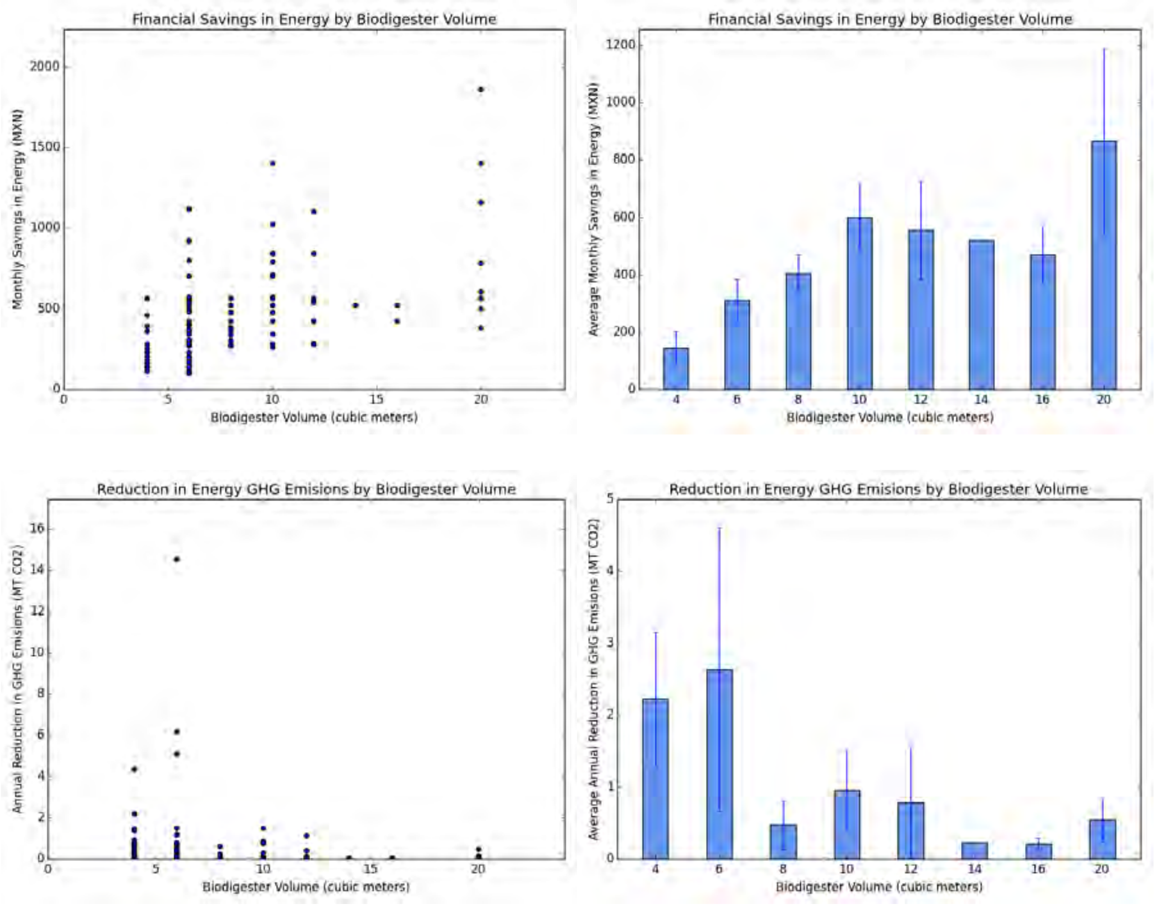

Figure 28: Top: Monthly savings in energy consumption. Bottom: GHG emissions reduction from fossil fuel displacement (error bars represent 95% CI)

Biodigester Effluent

The biodigester effluent is highly valued by the Domestic Sector users as a fertilizer and soil amendment. The great majority of users (93%) apply the effluent for this purpose, while only 7% of the users reported to not utilize the effluent. The effluent is applied to a great variety of crops including vegetables, fruit trees, grains, cacti and even ornamental plants. Users who apply the effluent reported to benefit from having bigger plants, improved quality of crops, higher productivity, more vigorous crops, faster growth, and to a lesser degree, improved plague resistance (see Figure 29). Only 5% of the users reported to see no positive changes when applying the effluent to their crops. Most users (61%) land apply the effluent manually with buckets. Other farms use sprayers (10%), pumps (9%), and trucks (8%) to disseminate the effluent.

Image 9: Left: User applying biodigester effluent manually with a bucket. Right: Nopales treated with biodigester effluent.

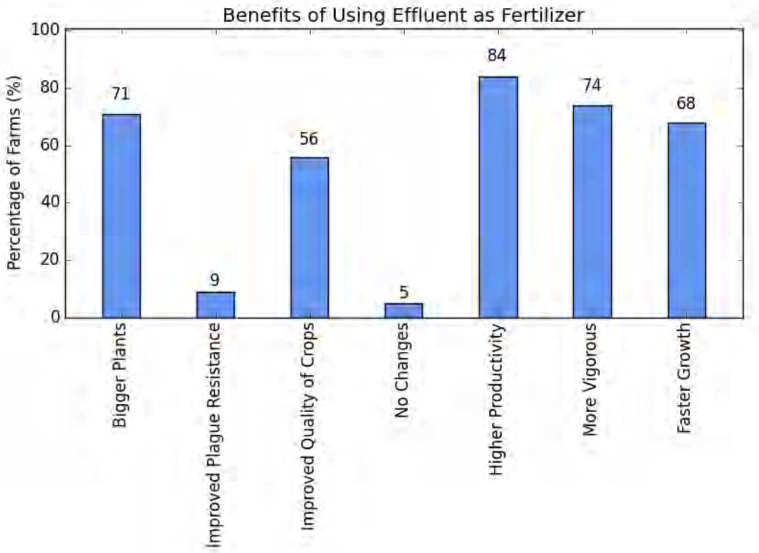

Figure 29: Most commonly reported effects of applying biodigester effluent on crops in backyard farms

The majority of users (75%) in the Domestic Sector do not use chemical fertilizers in growing their crops. However, one in every four users reported to save in chemical fertilizers now that they have the biodigester effluent as a source of fertilizer. Figure 30 shows the monthly savings users obtained from substituting chemical fertilizers by the effluent of the biodigester. Users with a 4 m^3 system save close to $100 MXN, and users with larger systems (14-20 m^3) save around $400 MXN on fertilizer per month. The users that had a high dependence on chemical fertilizers are able to save a significant amount of money, while the majority who never used chemical fertilizers are able to benefit from increased productivity of their agricultural activities.

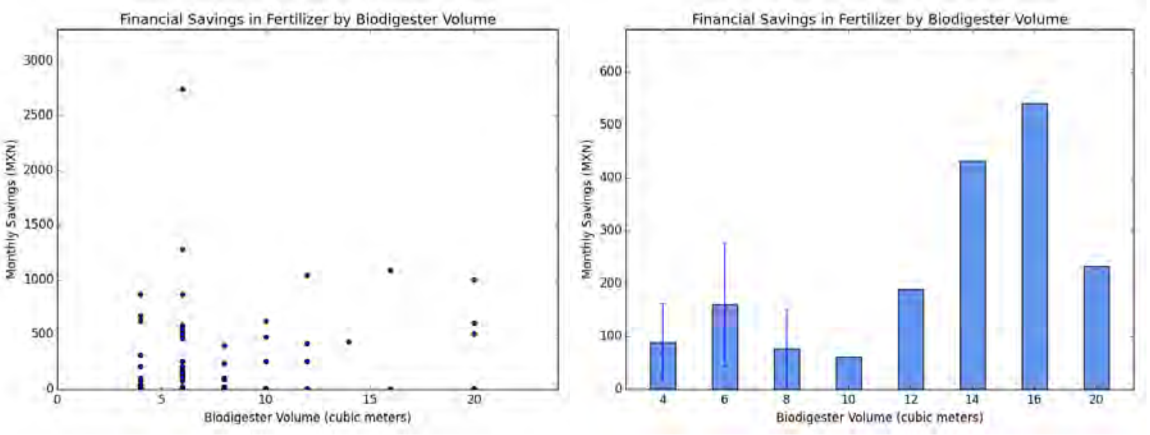

Figure 30: Fertilizer savings by biodigester volume (error bars represent 95% CI)

Benefits Summary

The digester users noted that the benefits included the following: fuel savings, cleaner sites, better smells, fewer insects, improved productivity of crops, fertilizer savings, less wood smoke, and fewer rodents. Fuel savings was the benefit most often noted by digester users.

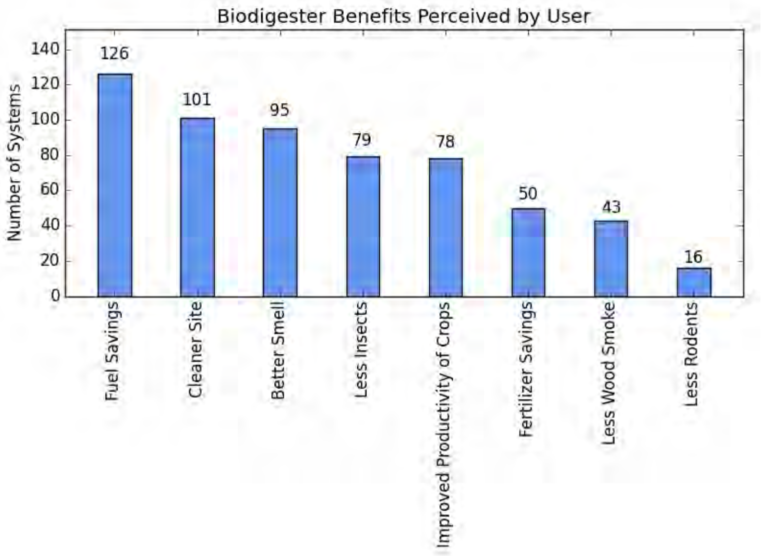

Figure 31: Mostly common perceived benefits by users

Most users in this sector save less than $500 MXN pesos per month due to the digester, while others reported saving up to $3,500 MXN (Figure 32). Savings for the systems are realized as operators have less need for fertilizers and fuel in the form of LPG and woodfuel. Users with a 4 – 6 m^3 system save on average $235 MXN per month, whereas the users with the larger system on the market (20 m^3) save on average $1,100 MXN per month. Users who displace both LPG and fertilizer consumption will save more than the average, and users who displace woodfuel consumption and didn’t use fertilizer in the baseline scenario will be saving less than the average.

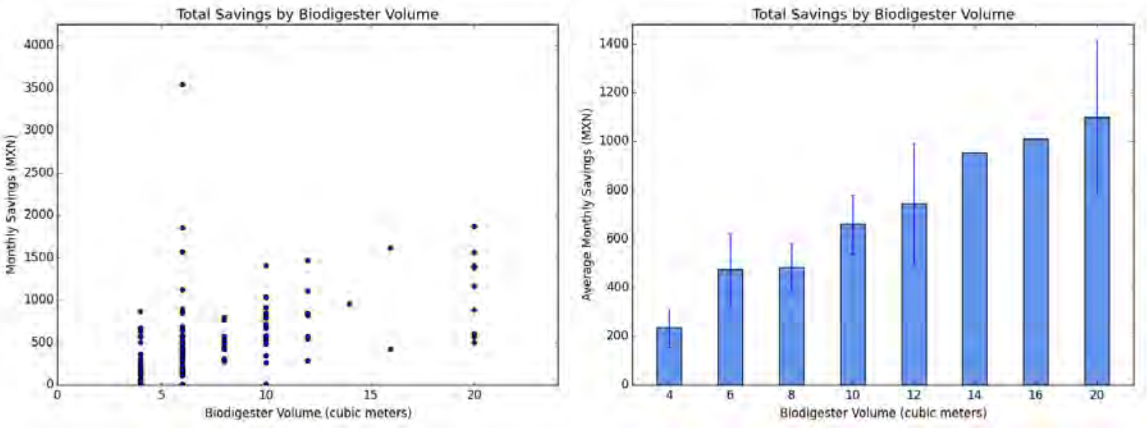

Figure 32: Total savings by biodigester volume (error bars represent 95% CI)

Most biodigesters in this sector produce annual GHG ERs below 5 MT of CO2e, while others produced up to 15 MT of CO2e according to the data they provided. GHG ERs for the systems are realized as operators have less need for fuel in the form of LPG and woodfuel, and treat their farm manure with the digester. Figure 33 shows that GHG ERs are highly variable and independent of the system volume. A 4m^3 system produces an annual average GHG ERs of 1.36 MT of CO2e, whereas the larger system on the market (20 m^3) produces an annual average GHG ERs of 1.18 MT of CO2e. The driving factors in determining the amount of GHG ERs are type of manure treated and displaced fuel, whereas system volume represents only the amounts of manure treated and displaced fuel. For this reason is not possible to correlate GHG ERs with system volume.

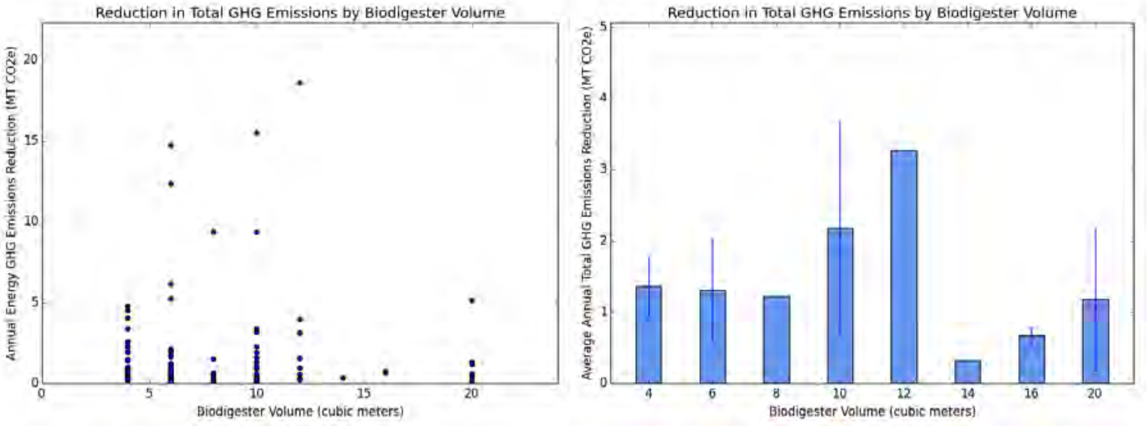

Figure 33: Total GHG emissions reduction by biodigester volume (error bars represent 95% CI)

Productive Sector Survey Results

Introduction

The Productive Sector is characterized by small to medium scale farms that have been assisted with a biodigester through livestock sector development programs managed by the government or private foundations. This section will describe the type and size of these farms, and the impact that the biodigester has made in the operations of the farms in the sector. The financial benefits stem from the use of biogas as an energy source that displaces LPG and electricity consumption. In addition, some beneficiaries see financial savings from the use of the biodigester effluent as fertilizer. The climate impact of these systems will be analyzed from two sources: the manure management practices and the displacement of fossil fuel consumption.

Image 10: Productive scale biodigester in Morelos

Productive Sector Characteristics

The Productive Sector is composed of small to medium scale farms that produce meat and/or dairy products. As shown in Figure 34, 83% of the digesters in this sector range between 25 and 120 m^3 in volume capacity and are tubular type, while 17% of the digesters are either 400 or 800 m^3 in volume and covered lagoon type. Due to the limited amount of large systems in this sector, any results drawn for smaller systems will be more accurate than the results drawn for larger systems. Most of the farms have less than 100 animals: 29% have less than 20 animals, and 18% have more than 500 animals. The only cattle types in this sector are bovine, porcine and ovine with 54%, 29% and 16% of the Productive Sector[11]

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[11] See Survey Methodology section for understanding precision and accuracy of statements and inferences made to the entire sector based on the surveyed sample.

respectively. The great majority (93%) of the farms in this sector are located in temperate climates, and only 7% in cold climates.

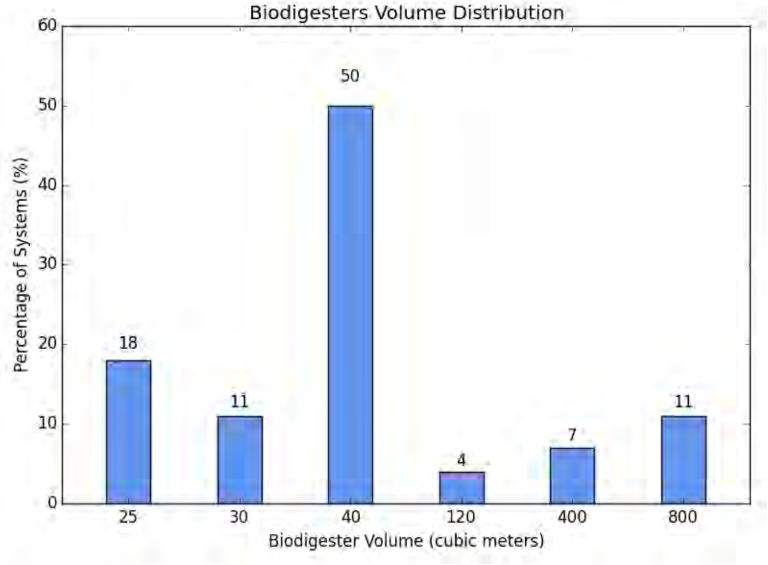

Figure 34: Biodigester volume distribution

The biodigesters in the Productive Sector are performing well in the country as 23 out of 28 (82%) are "working well" or "working well with minor issues" (see Figure 35). The 18% of the systems in the sector that are not working is because they had technical issue that the user was not willing to repair such a leaks in the geomembrane and problems with humidity. In other cases, the lack of periodic solids removal from the bottom of the digester has the system full of solids which makes it dysfunctional.

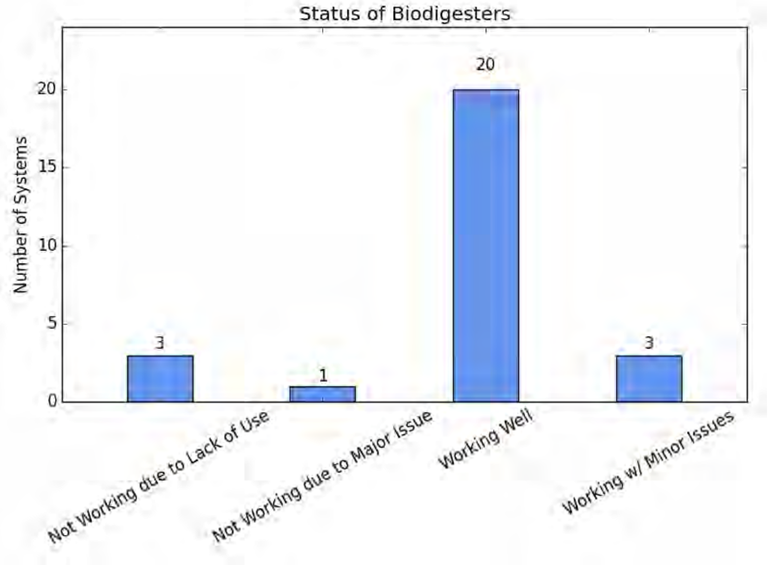

Figure 35: Biodigester systems status

Financing Mechanisms

Although the results show (see Financial and Climate Impacts of Biogas Production) that the Productive Sector biodigesters generate significant financial benefits for the farm's economy, the total cost of these systems is relatively high for these farms. Therefore, these systems are usually implemented through foundations and government assistance programs targeted towards livestock sector promotion. As shown in Figure 36 the financial mechanisms used to support the smaller systems in the sector are SEFOA, SEDAGRO, SDR and Produce Foundation. For the larger systems, FIRCO has provided 50% of the funding for those projects. Unknown (33%), KIVA (25%), and FIRCO (20%) funded projects have the highest rate of failure.

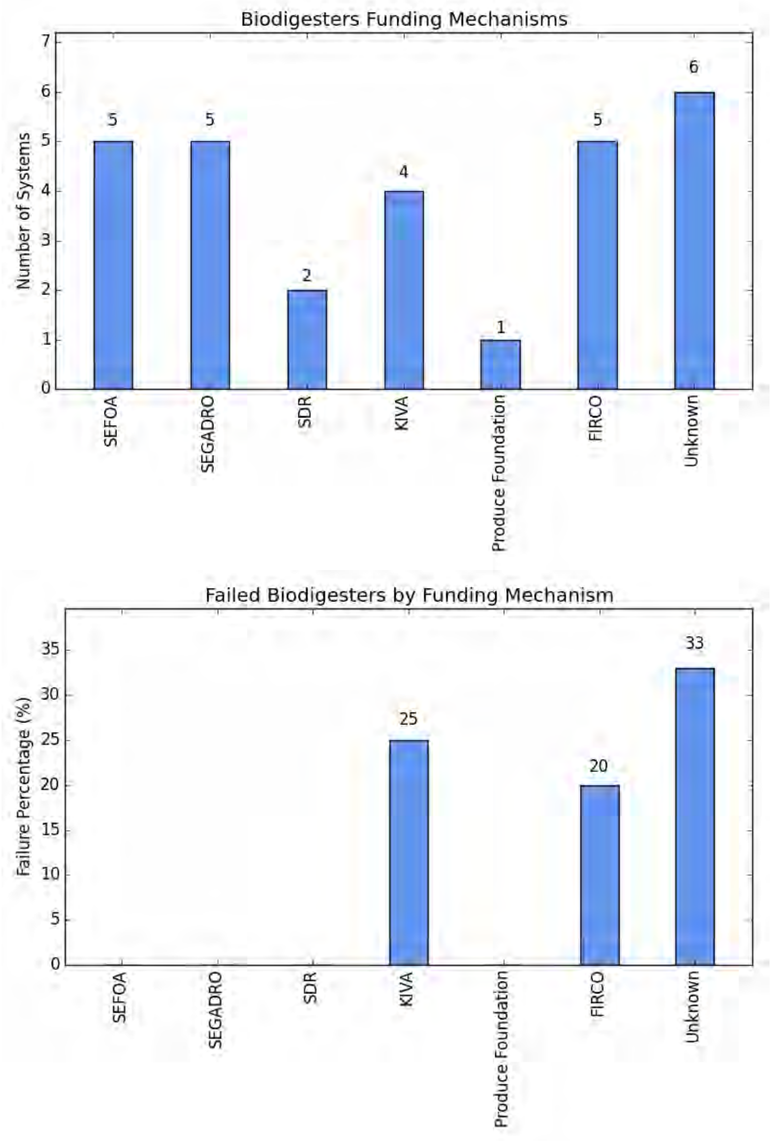

Figure 36: Top: Proportion of biodigesters by funding mechanisms. Bottom: Failed system rate by funding mechanism.

Manure Management

The installation of the biodigester in this sector guarantees significant impact in the manure management practices of the typical beneficiary. On average, 24% of the manure from all of the farms in the sector goes into the digester (Figure 38). In the baseline scenario (before the installation of the digester) the manure of the large systems (400-800 m^3), which accounts for 69% of the manure in the sector was disposed to aerated lagoons. The manure for the smaller systems was stored on the ground or in compost bins in order for the manure to be spread over fields during the growing season.

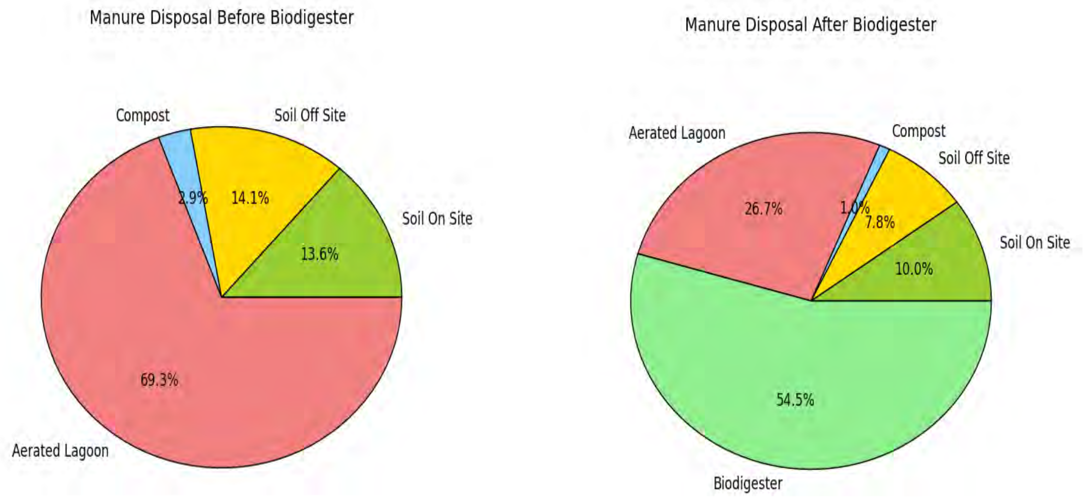

Figure 37: Manure disposal before and after the installation of the biodigester

A few of the farms (21%) treat 0-20% of their manure in the digester and 32% of the farms treat 20-50% of their manure in the digester (Figure 38). Only 21% of the sector sends 100% or more of their manure to the digester. Farmers send to an aerated lagoon, and to a lesser degree land apply, ship offsite, and compost the remaining manure that does not go to the digester. The digesters are supported by governmental programs and often are not big enough to accommodate the manure from all of the animals onsite. The great majority of the users (89%) only feed bovine or porcine manure into the digester, and only 11% of users combine different types of manure into the digester.

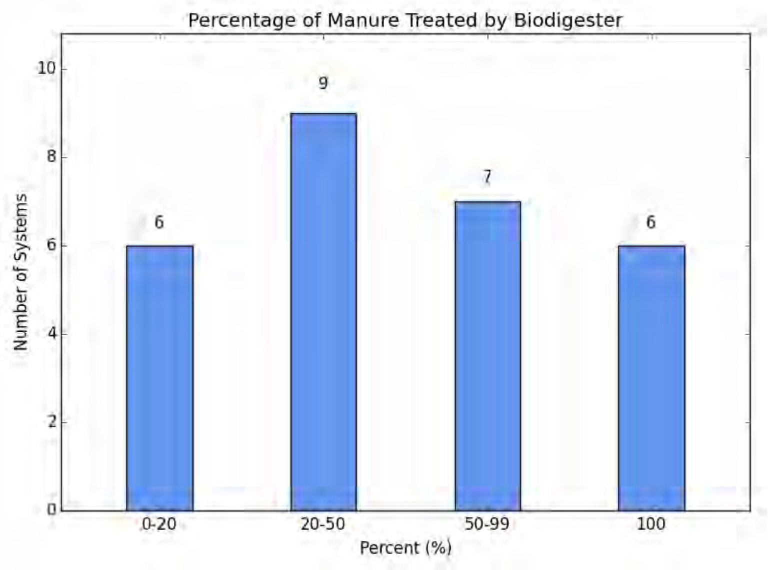

Figure 38: Percentage of manure treated by biodigesters

The amount of manure that a biodigester can treat depends primarily on the volume of the digester. As shown in Figure 22, users of 25-30 m^3 systems treat an average of 74 kg of manure a day, and users of 400-800 m^3 systems treat an average of 4,000 kg of manure a day. As we saw in Figure 37, the manure that is now being treated by the digester was stored in the ground or in aerated lagoons before the installation of the biodigester. When the manure is piled up on the ground or in aerated lagoons it tends to produce some methane gas that escapes into the atmosphere. With the installation of the biodigester this methane is now captured and burned. The reduction in GHG emissions from the manure treatment depends on the manure type and the site climate. As shown in Figure 39, the average GHG ERs for the 25-40 m^3 system is 3.9 MT of CO2e for manure treatment, and the average GHG ERs for the 400-800 m^3 systems is 618 MT of CO2e for manure treatment.

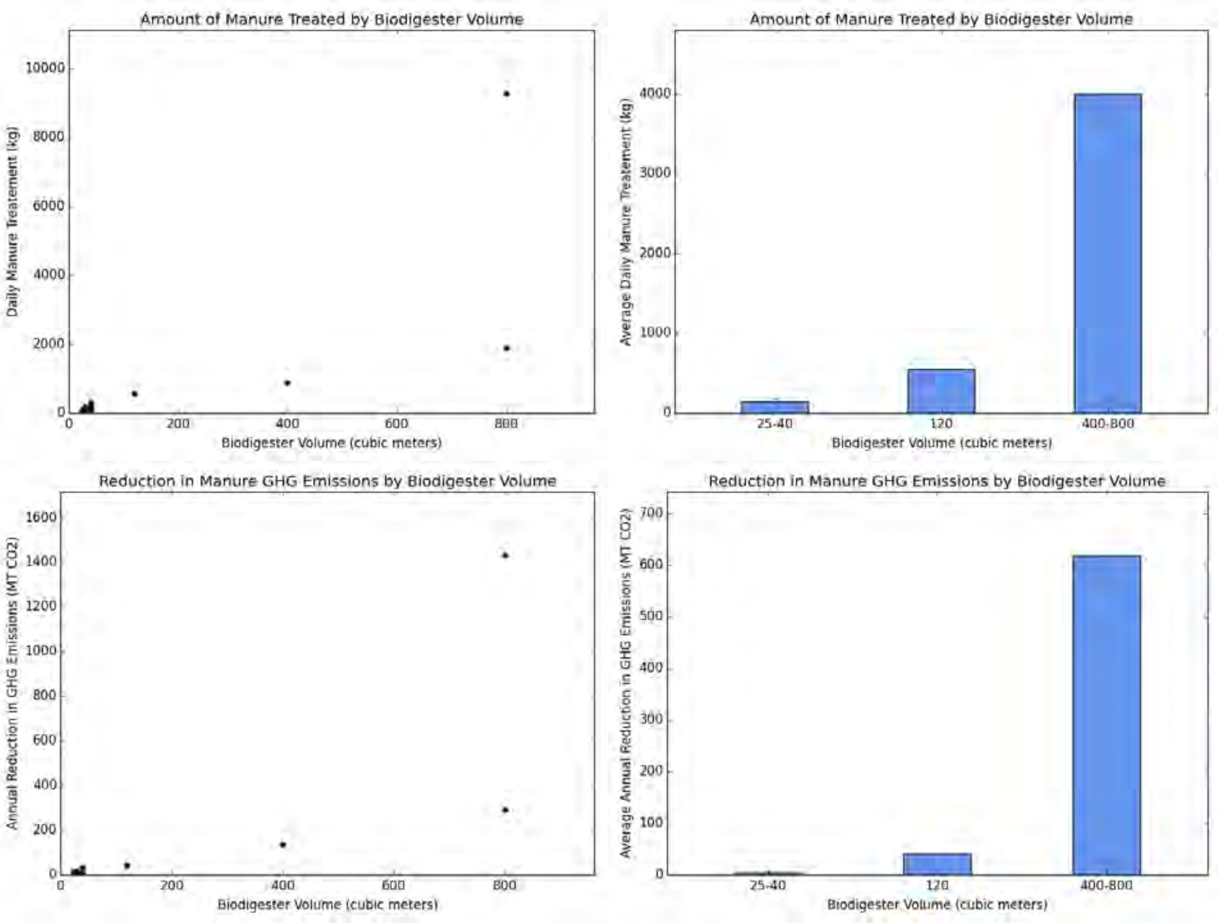

Figure 39: Top: Daily amount of manure treated by biodigesters. Bottom: Annual reduction in GHG emissions

Financial and Climate Impacts of Biogas Production

Users in the Productive Sector make use of biogas in several ways depending on the system size. Figure 40 shows the different uses that farms give to biogas. The smaller systems (25-120 m^3) tend to use it for a combination of household and commercial activities. The household uses include cooking and heating water, and the commercial uses include animal feed preparation, cheese preparation and heating of maternity pens. The larger systems (400-800 m^3) send the biogas to a methane burner. Given the baseline scenario the primary energy sources utilized for the household and commercial activities described above are LPG and electricity. The use of biogas tends to displace consumption of fossil fuels, which translates into financial savings for the user and greenhouse gas emissions reductions (GHG ERs). The following section will analyze the financial and climate impacts that the displacement of fossil fuel consumption by biogas has for different digester sizes.

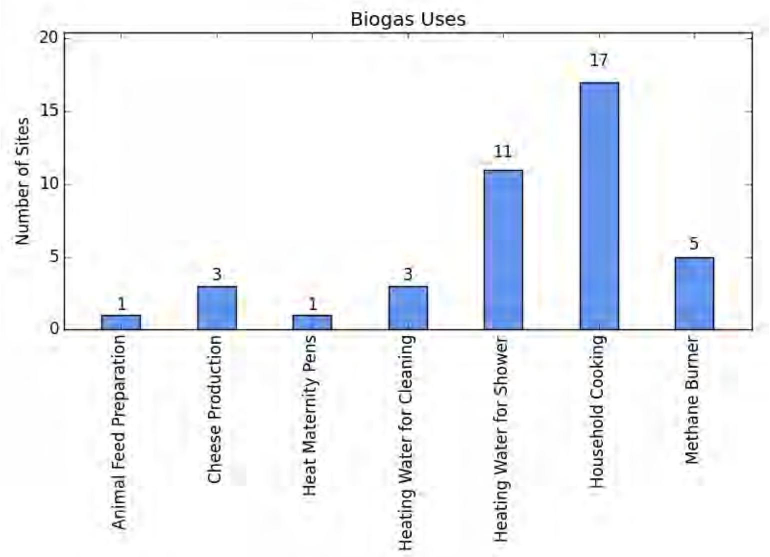

Figure 40: Biogas uses in the Productive Sector

LPG

The main source of energy for both household and commercial activities in the Productive Sector is LPG. Figure 41 shows that the displacement of LPG consumption for different digester volumes. On average, a 40 m^3 system provides a monthly reduction of 29 kg of LPG, whereas a 120 m^3 system provides a monthly reduction of 45kg of LPG. In terms of financial savings, a 40 m^3 system provides monthly savings of $372 MXN, whereas a 120 m^3 system provides monthly savings of $630 MXN from displaced LPG consumption.

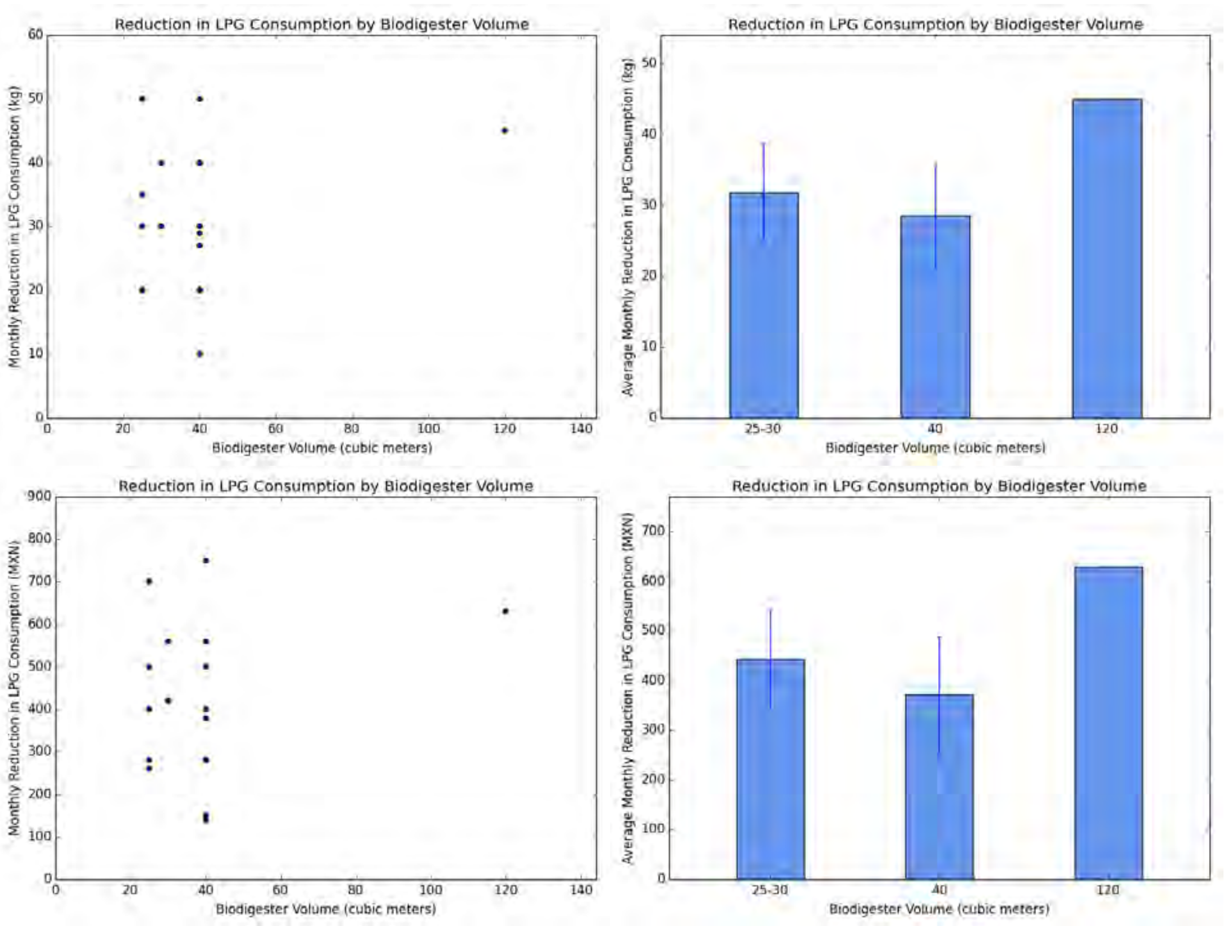

Figure 41: Top: Monthly reduction in LPG consumption. Bottom: Monthly savings in LPG consumption (error bars represent 95% CI)

For each system volume, the annual GHG ERs from LPG was calculated in MT of CO2e (Figure 42). On average, a 40 m^3 system provides an annual reduction of 0.32 MT of CO2e, whereas a 120 m^3 system provides an annual reduction of 0.51 MT of CO2e, through displaced LPG consumption.

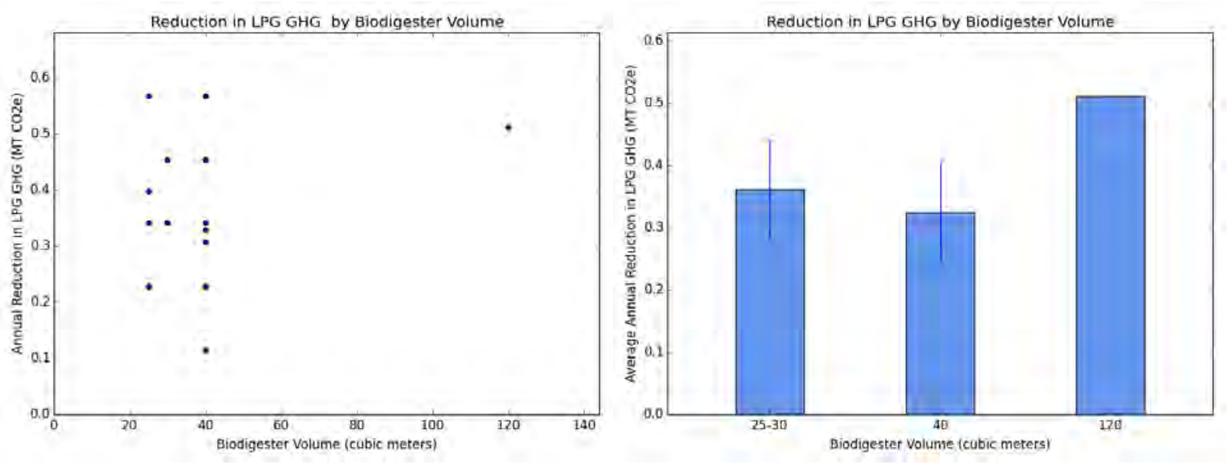

Figure 42: Reduction in LPG GHG emissions by biodigester volume (error bars represent 95% CI)

Electricity

There was only one case where electricity consumption was displaced by the use of biogas. This occurred in a swine farm that used electric bulbs in order to heat the maternity pens in the baseline scenario. With the installation of the biodigester, the use of the heating bulbs was replaced by biogas burners. As shown in Figure 43, this farm displaces an average of 273 kWh per month, which translates into $600 MXN in monthly savings for displaced electricity.

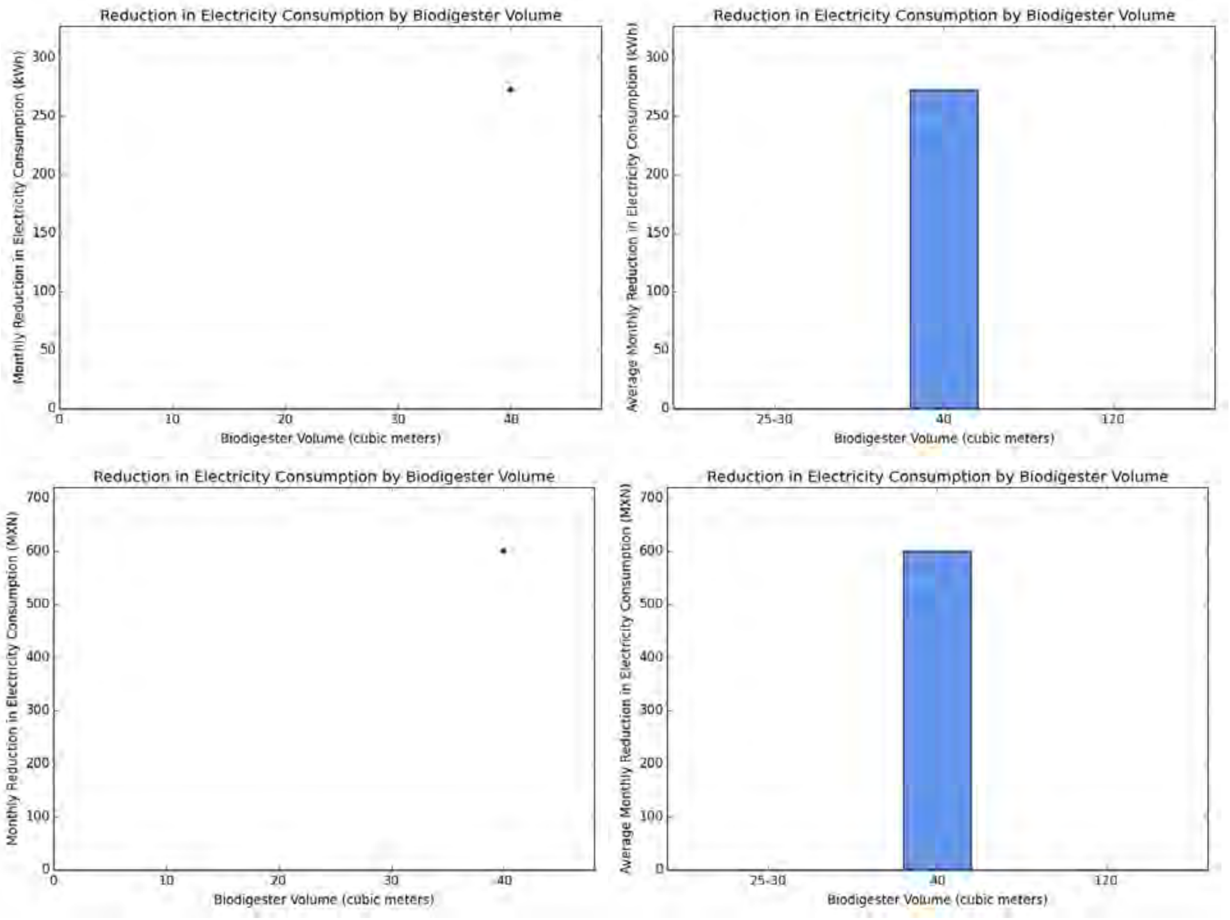

Figure 43: Top: Monthly reduction in electricity consumption. Bottom: Monthly savings in electricity consumption.

The GHG ERs derived from the displacement of electricity consumption are shown in Figure 44. This farm provides an annual reduction of 2.62 MT of CO2e.

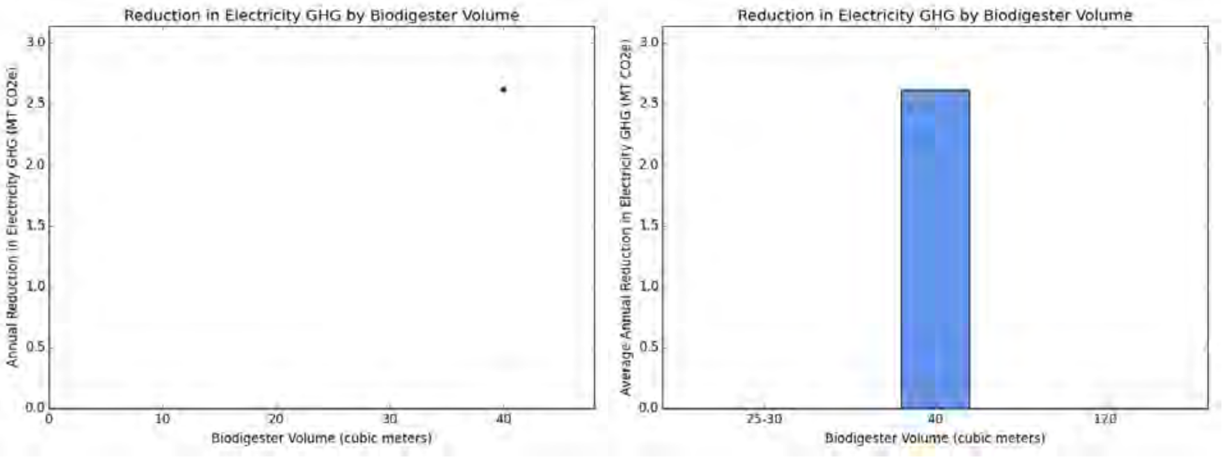

Figure 44: Reduction in electricity GHG emissions by biodigester volume

Summary - Financial and Climate Impacts of Biogas Production

The displacement of LPG and electricity consumption generated by the use of biogas can result in significant financial savings and GHG ERs. The financial impact depends mostly on the quantity and cost of fuel displaced. The biodigester size determines the amount of biogas available, and the more biogas available, the more fossil fuel is displaced, hence higher savings. In the other hand, the level of impact in GHG ERs depends primarily on the type of fuel displaced. This is because electricity has a higher GHG emission potential than LPG. The financial savings and GHG ERs from the displacement of fossil fuels by the use of biogas are shown in Figure 45.

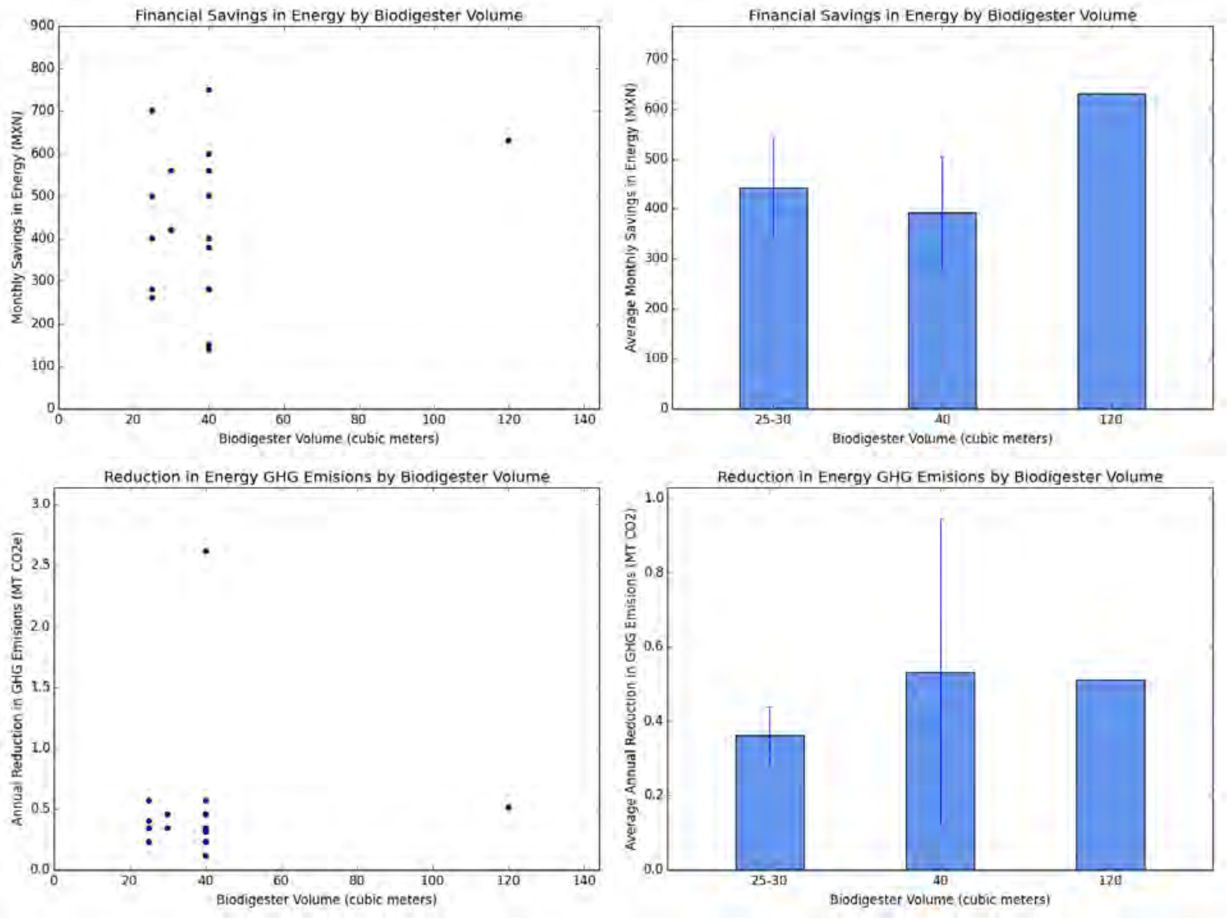

Figure 45: Left: Monthly savings in energy consumption. Right: GHG emissions reduction from fossil fuel displacement. (error bars represent 95% CI)

Biodigester Effluent

The biodigester effluent is highly valued by the Domestic Sector users as a fertilizer and soil amendment. The great majority of users (93%) apply the effluent for this purpose, while only 7% of the users reported to not utilize the effluent. The effluent is applied to a great variety of crops including vegetables, fruit trees, grains, cacti and even ornamental plants. Users who apply the effluent reported to benefit from having higher productivity, more vigorous plants, faster growth, and to a lesser degree, improved quality of crops and improved plague resistance (see Figure 46). Only 4% of the users reported to see no positive changes when applying the effluent to their crops. The most common ways that users in this sector applied the effluent to the crops was by pump with 39% of the users, and by truck with 32% of the users. Other ways the effluent is applied to the ground are manually with buckets (14%) and with sprayer (4%).

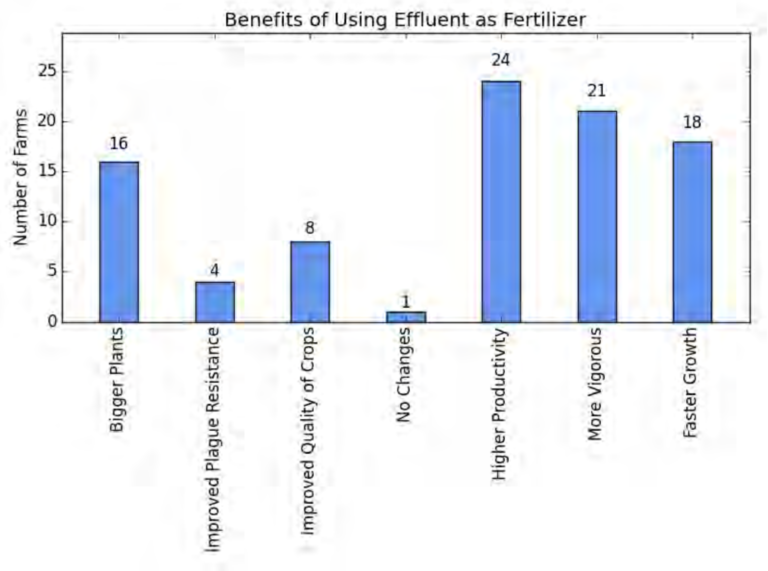

Figure 46: Most commonly reported effects of applying biodigester effluent on crops in productive sector farms

The majority of users (68%) in the Productive Sector do not use chemical fertilizers in growing their crops. However, 32% of users reported to save in chemical fertilizers now that they have the biodigester effluent as a source of fertilizer. Figure 30 shows the monthly savings users obtained from substituting chemical fertilizers by the effluent of the biodigester. Users with a 25 m^3 system save $170 MXN, and users with an 800 m^3 save around $10,900 MXN on fertilizer per month. The users that had a high dependence on chemical fertilizers are able to save a significant amount of money, while the majority who never used chemical fertilizers are able to benefit from increased productivity of their agricultural activities.

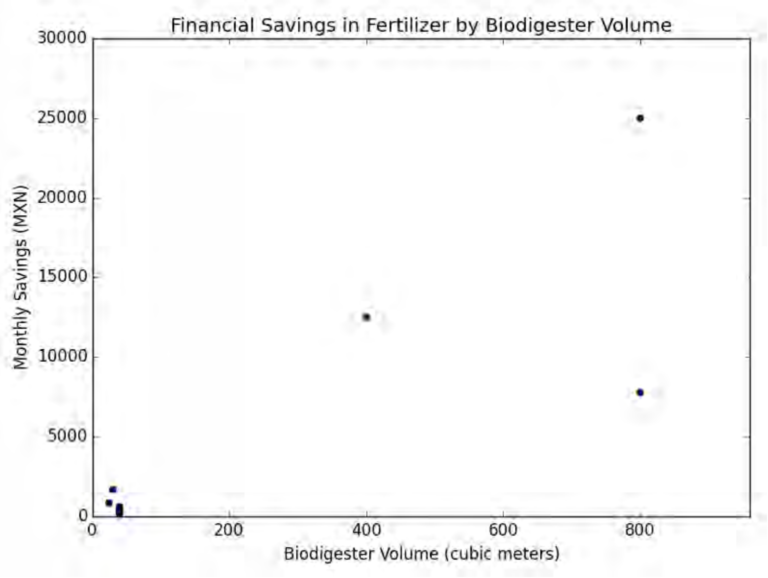

Figure 47: Fertilizer savings by biodigester volume

Benefits Summary

The digester users noted that the benefits included the following: fuel savings, cleaner sites, better smells, fewer insects, improved productivity of crops, fertilizer savings, and fewer rodents. Fuel savings was the benefit most often noted by digester users.

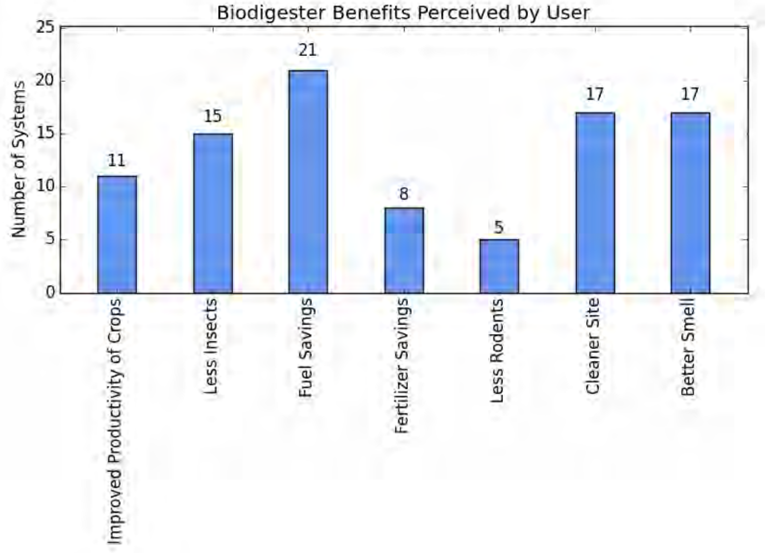

Figure 48: Mostly common perceived benefits by users

The total savings as result of the financial benefits from the biodigester are shown in Figure 32. Savings for the systems are realized as operators have less need for fertilizers and fossil fuels in the form of LPG and electricity. Users with a 25-40 m^3 system save on average $615 MXN per month, whereas the users with the larger system on the market (400-800 m^3) save on average $15,100 MXN per month. Users who displace both LPG and fertilizer consumption will save more than the average, and users who didn't use fertilizer in the baseline scenario will be saving less than the average.

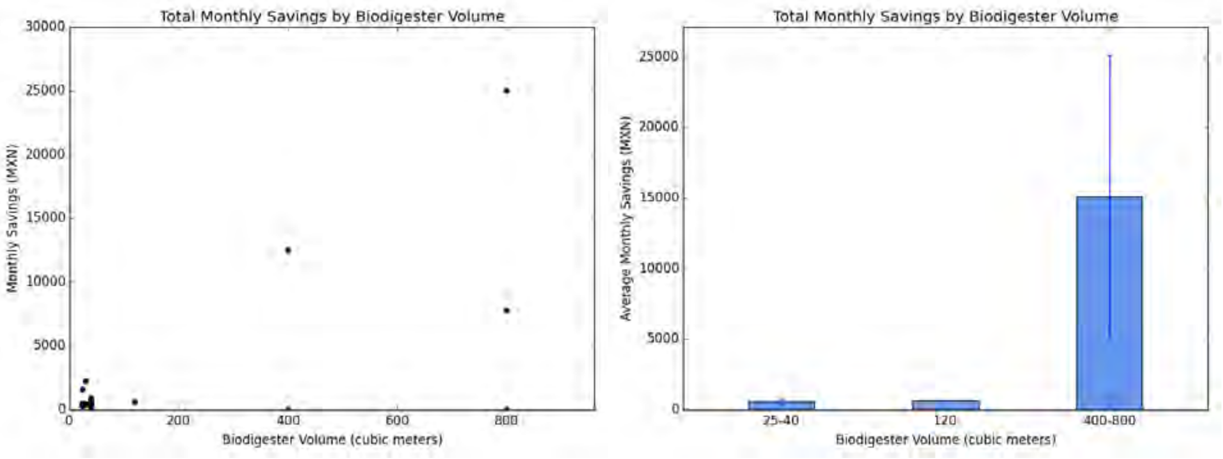

Figure 49: Total savings by biodigester volume (error bars represent 95% CI)

GHG ERs for the systems are realized as operators have less need for fossil fuels in the form of LPG and electricity, and treat electricity, and treat their farm manure with the digester.

Figure 50 shows that GHG ERs for this sector vary considerably with system volume. A 25-40m^3 system produces an annual average GHG ERs of 4.2 MT of CO2e, whereas a 400-800 m^3 produces an annual average GHG ERs of 618 MT of CO2e.

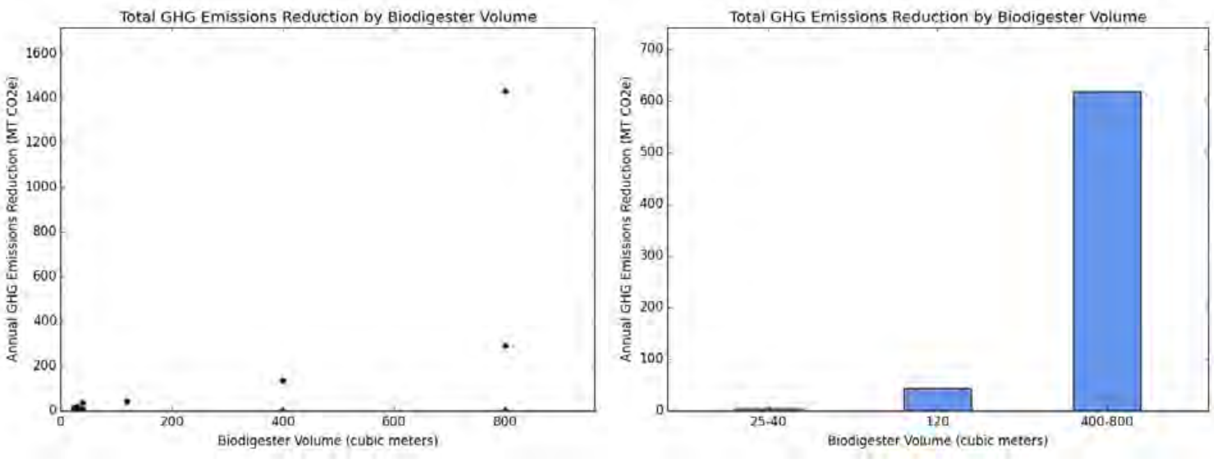

Figure 50: Total GHG emissions reduction by biodigester volume

Industrial Sector Survey Results

Introduction

The Industrial Sector is characterized by large scale dairy or swine farms that have been assisted with a biodigester through livestock sector development programs managed by the government or private companies that seek to sell CERs. This section will describe the type and size of these farms, and the impact that the biodigester has made in the operations of the farms in the sector. The financial benefits stem from the use of biogas as an energy source that displaces electricity and LPG consumption. In addition, some farms see financial savings from the use of the biodigester effluent as fertilizer. The climate impact of these systems will be analyzed from two sources: the manure management practices and the displacement of fossil fuel consumption.

Image 11: Industrial scale biodigester in Jalisco

Industrial Sector Characteristics

The Industrial Sector is composed of large scale farms that produce meat and/or dairy products. As shown in Figure 51, 62% of the digesters in this sector range between 1,000 and 10,000 m3 in volume capacity, and 10% of the digesters are over 40,000 m3 in volume. Most of the farms have between 1,000 and 10,000 animals: 10% have less than 1,000 animals, and 19% have more than 10,000 animals. The only cattle types in this sector are porcine and bovine and ovine with 67% and 37% of the Industrial

Sector respectively. The majority (57%) of the farms in this sector are located in temperate climates, 42% of the farms are located in temperate climates, and only 1% are located in cold climates.

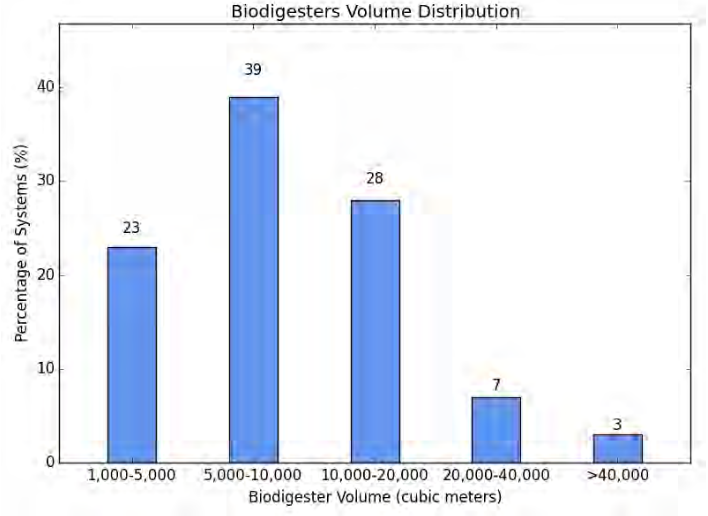

Figure 51: Biodigester volume distribution

The biodigesters in the Industrial Sector are performing well in the country as 94 out of 109 (86%) are “working well” or “working well with minor issues” (see Figure 49). The 14% of the systems in the sector that are not working is mainly due to the lack of periodic solids removal from the bottom of the digester which has the system full of solids and makes it dysfunctional. The majority of the systems that reported to be “working well with minor issues” is also due to the high level of solids in the bottom of the digester. These systems had been filled completely with solids, and the owner decided to open the digester in order to remove the solids. Due to the high cost of a complete solids extraction for these large systems, most of the owners have opted to partially remove the top solids in order to keep the system operational with about half or less of the original capacity. The owner is now incurring in high operational costs in order to keep operational a low performing system. For two of the systems that are currently working well, the methane burner is not working. While the farm still gets the treatment of the manure benefit, these systems are producing higher GHG emissions than the baseline scenario.

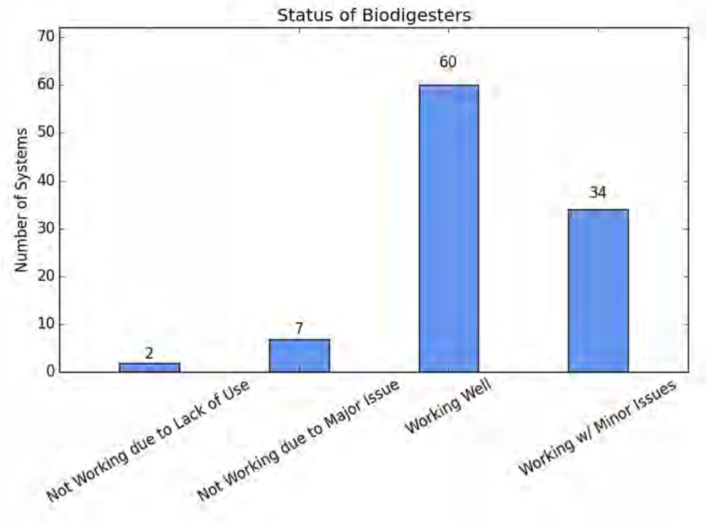

Figure 52: Biodigester systems status

Financing Mechanisms

Although the results show (see Financial Benefits section) that the productive scale biodigesters generate significant financial benefits for the farm's economy, the total cost of these systems is relatively high for these farms. Therefore, many of these systems have been installed with financial support from either FIRCO or CDM funding (Ag Cert) (Figure 53). FIRCO usually provides a 50% subsidy and the remaining 50% is covered by the farm either through third party loans or upfront investment. The Ag Cert systems were entirely financed by Ag Cert with no cost to the farm. Ag Cert benefited from selling the CERs that resulted from the operation of these systems. Ag Cert has the highest failure rate in the sector with 15% of their systems currently not working.

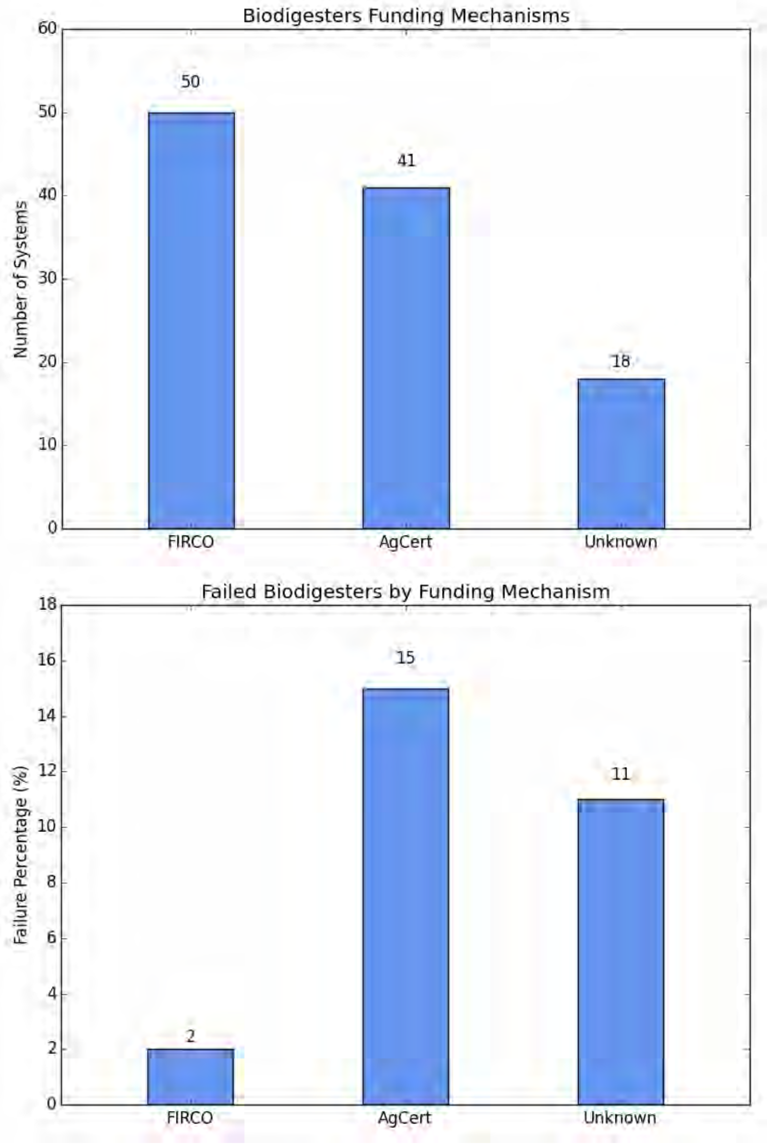

Figure 53: Top: Proportion of biodigester by funding mechanisms. Bottom: Failed system rate by funding mechanism.

Manure Management

The installation of the biodigester in this sector guarantees significant impact in the manure management practices of the typical beneficiary. On average, 33% of the manure from all of the farms in the sector goes into the digester (Figure 55). In the baseline scenario (before the installation of the digester) the manure was disposed to the soil or compost bins, and to a lesser degree deposited in aerated lagoons.

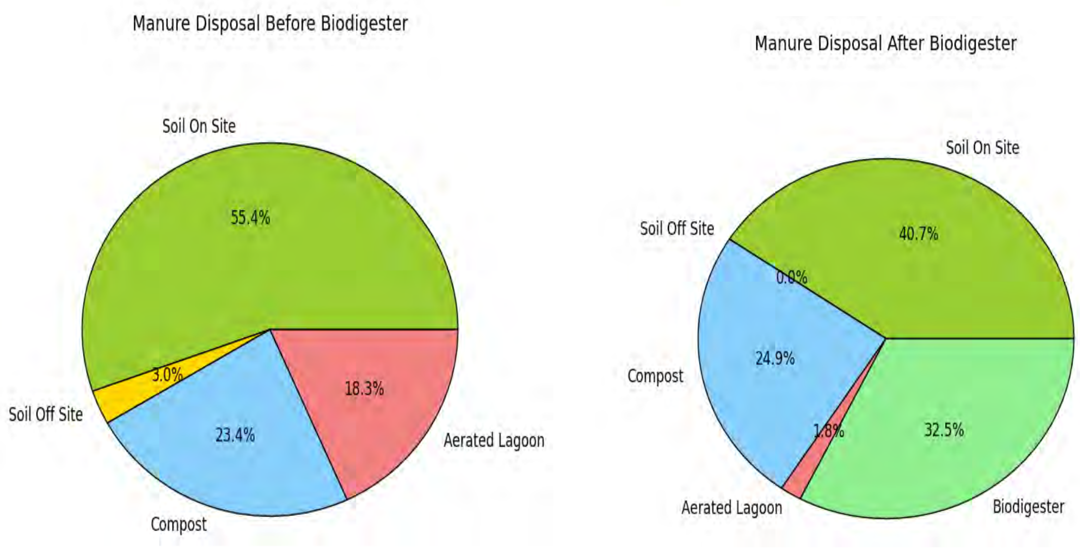

Figure 54: Manure disposal before and after the installation of the biodigester

Most of the farms (63%) treat 100% of their manure in the digester and 42% of the farms treat less than 20% of their manure in the digester (Figure 55). After the installation of the digester, farms have considerably reduced the amount of manure that is deposited into aerated lagoons, but still use the excess manure for land applications. The great majority of the users (97%) only feed bovine or porcine manure into the digester, and only 3% of users combine bovine and porcine manure into the digester.

Image 12: Manure sedimentation tank in Chihuahua

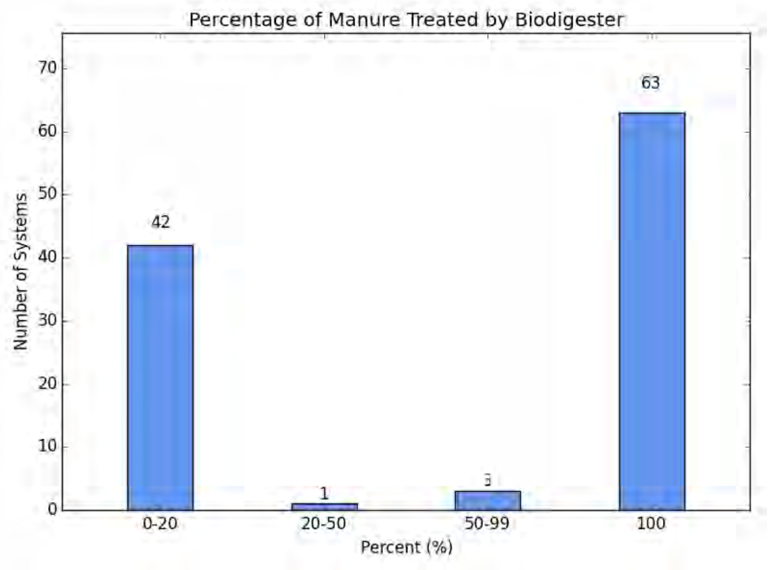

Figure 55: Percentage of manure treated by biodigesters

The amount of manure that a biodigester can treat depends primarily on the volume of the digester. As shown in Figure 56, a 1,000-10,000 m^3 system treats on average 8,800 kg of manure a day, and a 10,000-20,000 m^3 system treats on average 21,900 kg of manure a day. As we saw in Figure 54, the manure that is now being treated by the digester was stored in the ground or in aerated lagoons before the installation of the biodigester. When the manure is piled up on the ground or in aerated lagoons it tends to produce some methane gas that escapes into the atmosphere. With the installation of the biodigester this methane is now captured and burned. The reduction in GHG emissions from the manure treatment depends on the manure type and the site climate. As shown in Figure 56, the average GHG ERs for the 1,000-10,000 m^3 system is 1,400 MT of CO2e for manure treatment, and the average GHG ERs for the 10,000-20,000 m^3 systems is 2,700 MT of CO2e for manure treatment.

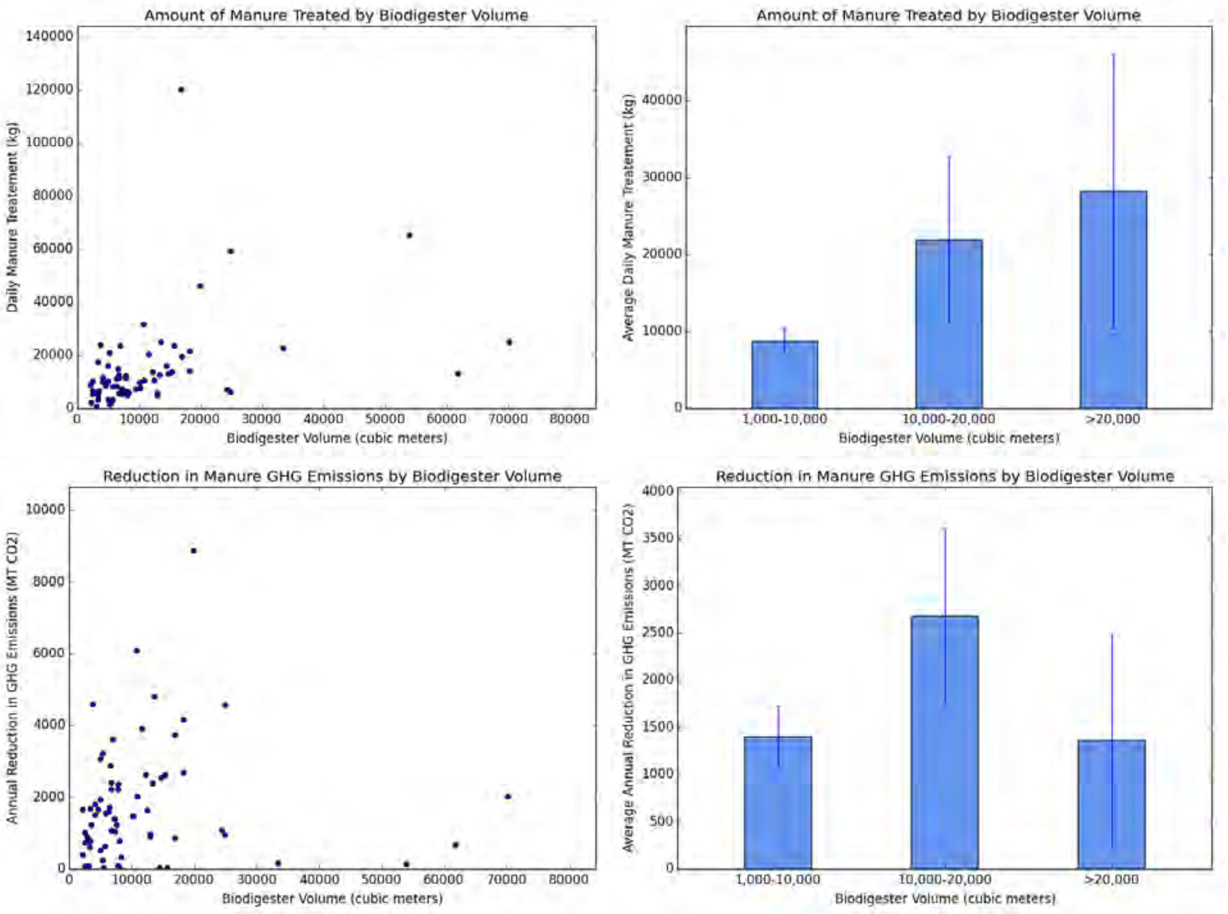

Figure 56: Top: Daily amount of manure treated by biodigesters. Bottom: Annual reduction in GHG emissions (error bars represent 95% CI)

Financial and Climate Impacts of Biogas Production

Users in the Industrial Sector make use of biogas in two main ways: methane burner and electricity generation. Figure 57 shows the different uses that farms give to biogas. The majority of the users (61%) do not utilize biogas other than for burning the methane. In part, this is because 38% of the users received the biodigester by Ag Cert with the focus of selling the CERs, and even though some users invested in an electricity generator, most users have not made this investment. Given the baseline scenario the primary energy sources utilized for the farm activities described above are electricity and LPG. The use of biogas tends to displace consumption of fossil fuels, which translates into financial savings for the user and greenhouse gas emissions reductions (GHG ERs). The following section will analyze the financial and climate impacts that the displacement of fossil fuel consumption by biogas has for different digester sizes.

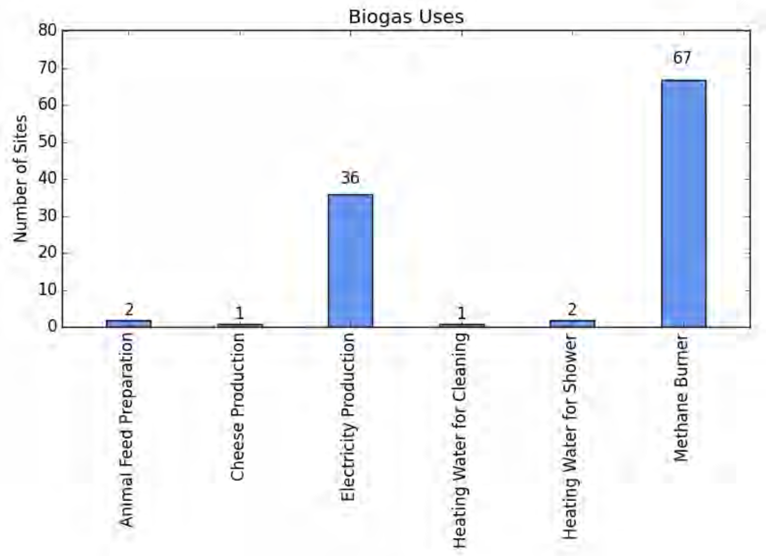

Figure 57: Biogas uses in the Industrial Sector

Electricity

The main source of energy for the farm activities in the Industrial Sector is electricity. Figure 58 shows the displacement of electricity consumption for different digester volumes. On average, the 1,000-5,000 m^3 systems provide a monthly reduction of 9,400 kWh of electricity, whereas the 10,000-20,000 m^3 systems provide a monthly reduction of 18,600 kWh. In terms of financial savings, the 1,000-5,000 m^3 systems provide monthly savings of $20,000 MXN, whereas a 10,000-20,000 m^3 systems provide monthly savings of $39,500 MXN from displaced electricity consumption. The displacement of electricity consumption depends in one part on the operating capacity of the generator, but also on the performance of the generator. Some generators do not deliver their potential due to frequent technical failures that result in high down times. This reduces their financial viability, and in some cases incur is financial losses for the farm due to the high maintenance cost.

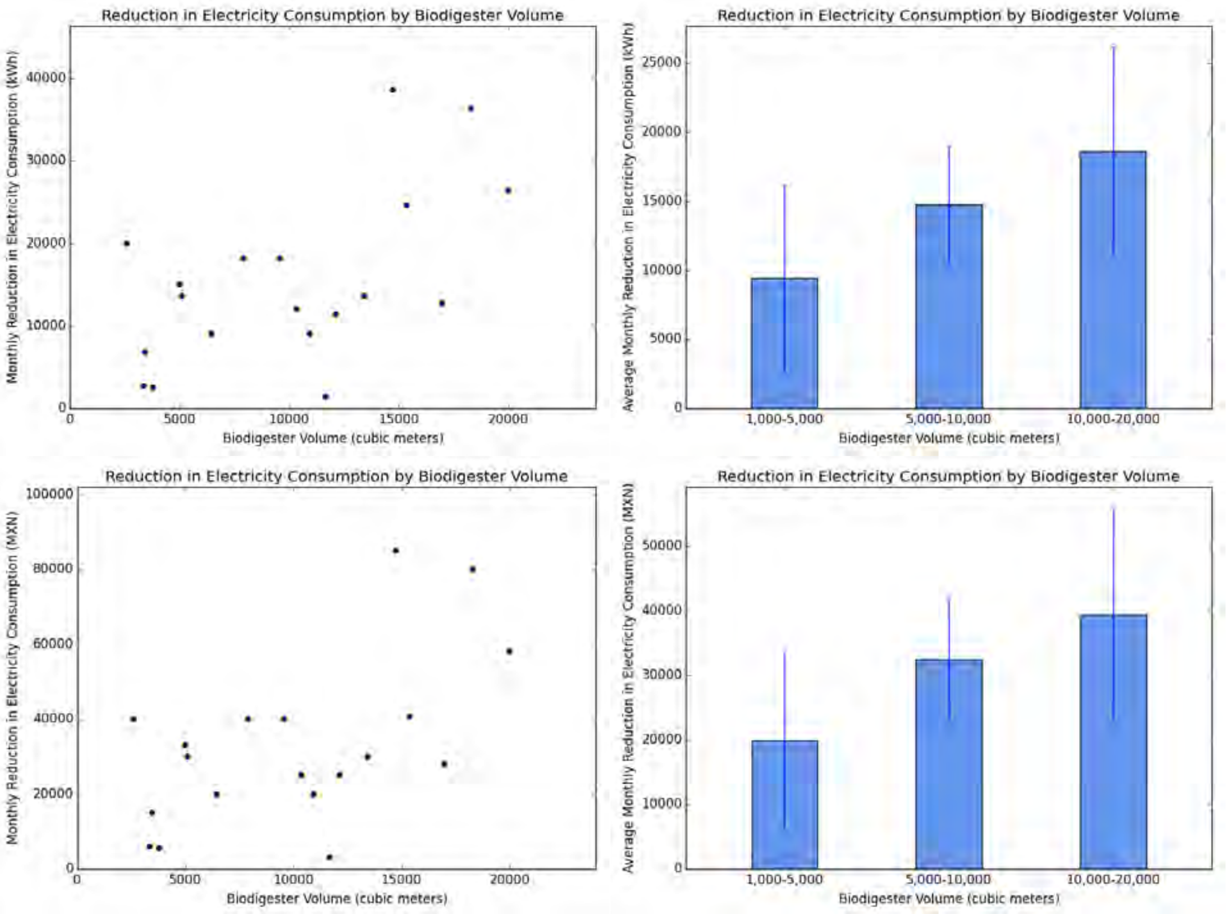

Figure 58: Top: Monthly reduction in electricity consumption. Bottom: Monthly savings in electricity consumption (error bars represent 95% CI)

For each system volume, the annual GHG ERs from displacement of electricity consumption was calculated in MT of CO2e (Figure 59). On average, the 1,000-5,000 m^3 systems provide annual GHG ERs of 91 MT of CO2e, whereas the 10,000-20,000 m^3 systems provide annual GHG ERs of 179 MT of CO2e, through displaced electricity consumption.

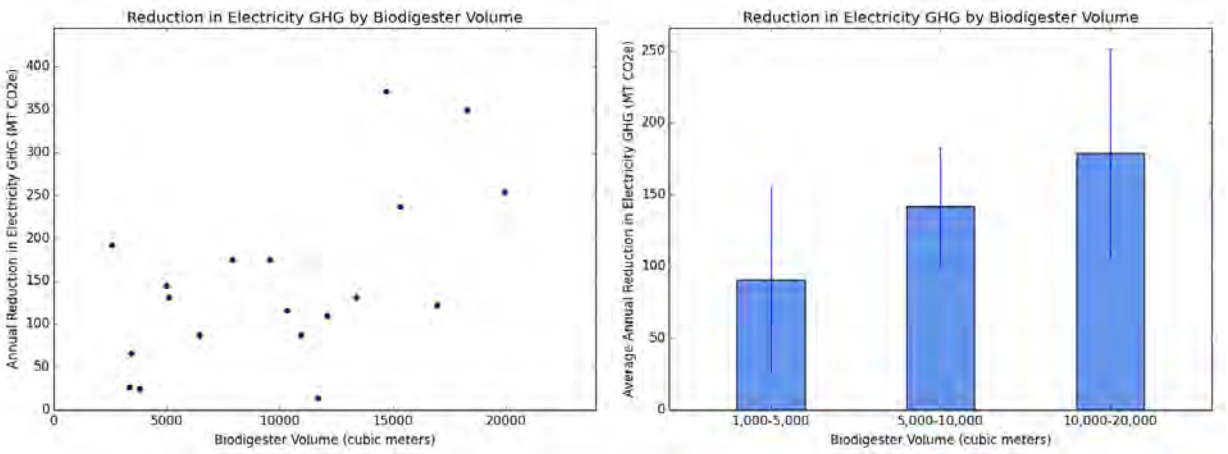

Figure 59: Reduction in electricity GHG emissions by biodigester volume (error bars represent 95% CI)

LPG

There were only two case where LPG consumption was displaced by the use of biogas. In one of the cases a swine farm used the biogas to heat the water for the daily showers of over 30 farm employees. In the other case a dairy farm used biogas for the cheese preparation process. As shown in Figure 60, these farms displaced an average of 1,300 kg of LPG per month, which translates into $18,400 MXN in monthly savings for displaced LPG. These ingenious uses of biogas provide substantial savings with a relatively low investment.

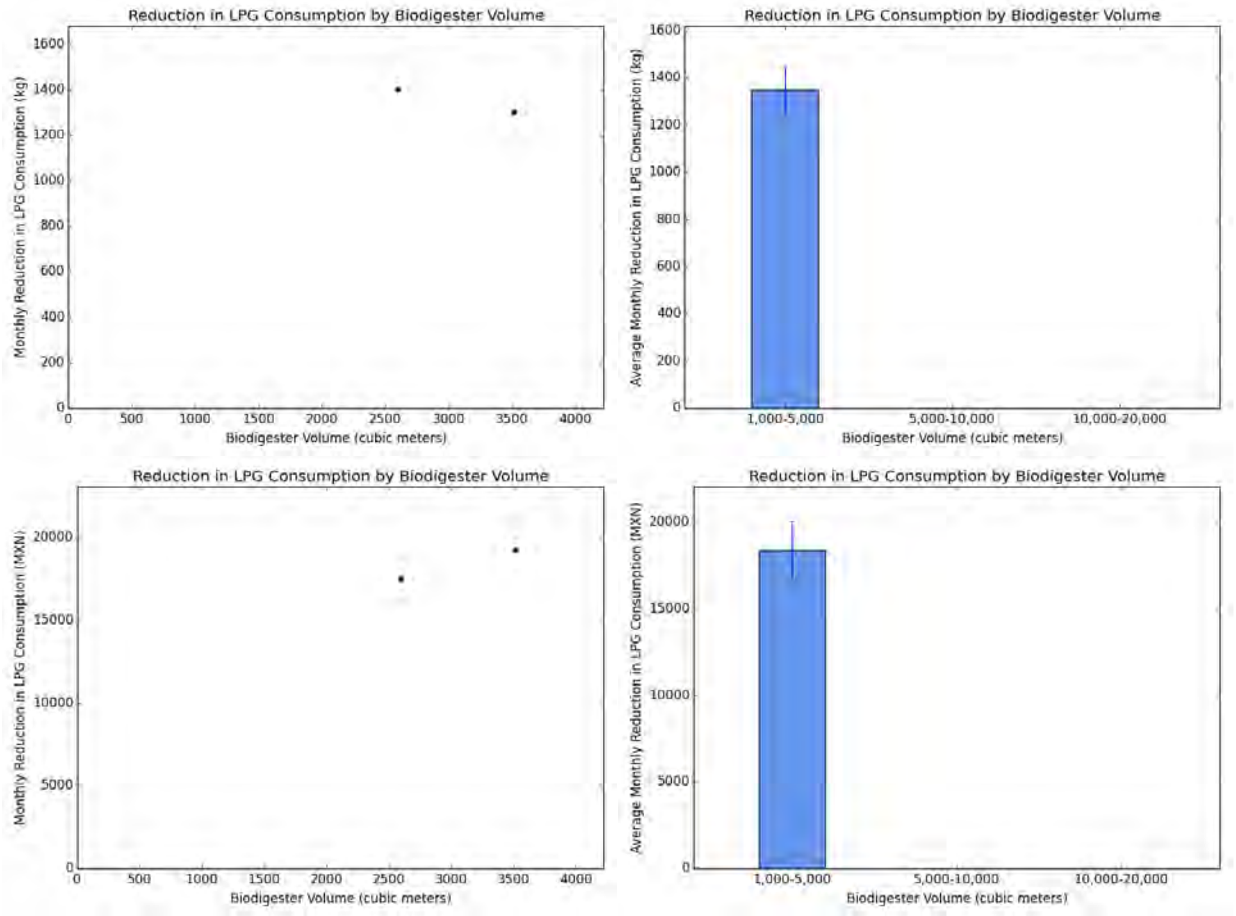

Figure 60: Top: Monthly reduction in LPG consumption. Bottom: Monthly savings in LPG consumption. (error bars represent 95% CI)

The GHG ERs derived from the displacement of LPG consumption is shown in Figure 61. These farms provide an annual reduction of 15.3 MT of CO2e.

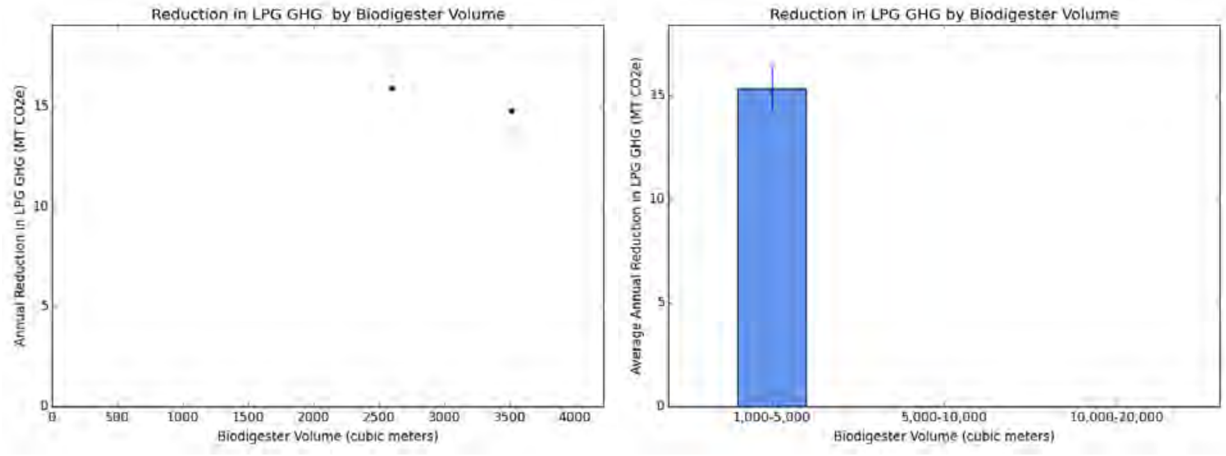

Figure 61: Reduction in LPG GHG emissions by biodigester volume (error bars represent 95% CI)

Summary - Financial and Climate Impacts of Biogas Production

The displacement of electricity and LPG consumption generated by the use of biogas can result in significant financial savings and GHG ERs. The financial impact depends mostly on the quantity and cost of fuel displaced. The biodigester size determines the amount of biogas available, and the more biogas available, the more fossil fuel is displaced, hence higher savings. In the other hand, the level of impact in GHG ERs depends primarily on the type of fuel displaced. This is because electricity has a higher GHG emission potential than LPG. The financial savings and GHG ERs from the displacement of fossil fuels by the use of biogas are shown in Figure 62.

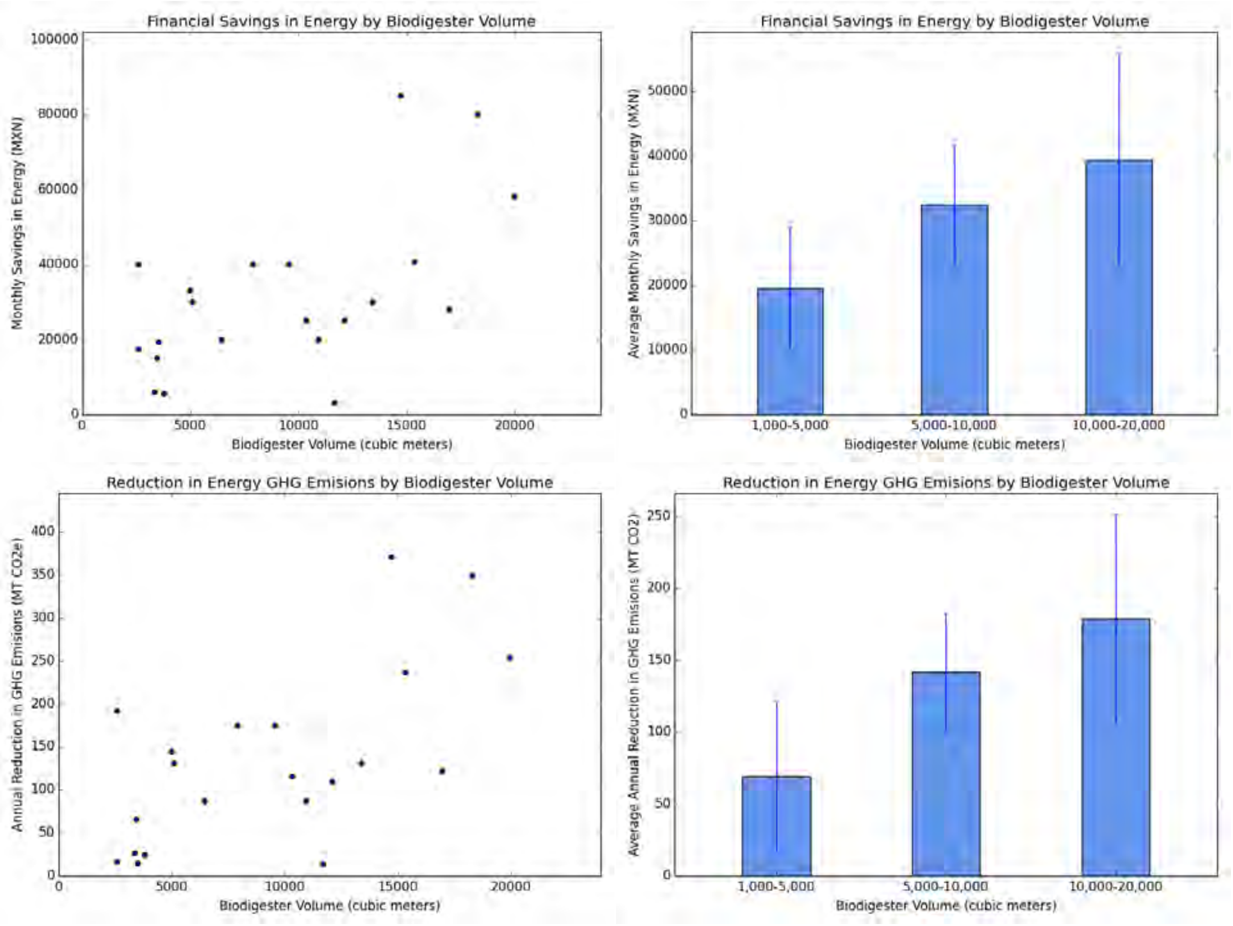

Figure 62: Top: Monthly savings in energy consumption. Bottom: GHG emissions reduction from fossil fuel displacement (error bars represent 95% CI)

Biodigester Effluent

The biodigester effluent is used by the Industrial Sector users as a fertilizer and soil amendment. The majority of users (59%) apply the effluent for this purpose, while a considerable 41% of the users reported to not utilize the effluent. In some cases the farmers reported to not use the effluent because of legal barriers that prevented them from using it for crop irrigation purposes. The effluent is applied to animal feed crops such as corn, wheat and pasture. Users who apply the effluent reported to benefit from having more vigorous plants, higher productivity, faster growth, bigger plants and to a lesser degree, improved quality of crops and improved plague resistance (see Figure 63). Only 5% of the users reported to see no positive changes when applying the effluent to their crops. The most common ways that users in this sector applied the effluent to the crops was by pump with 54% of the users, and by gravity with 41% of the users. Other ways the effluent is applied to the ground are with sprayer (9%) and with a truck (3%).

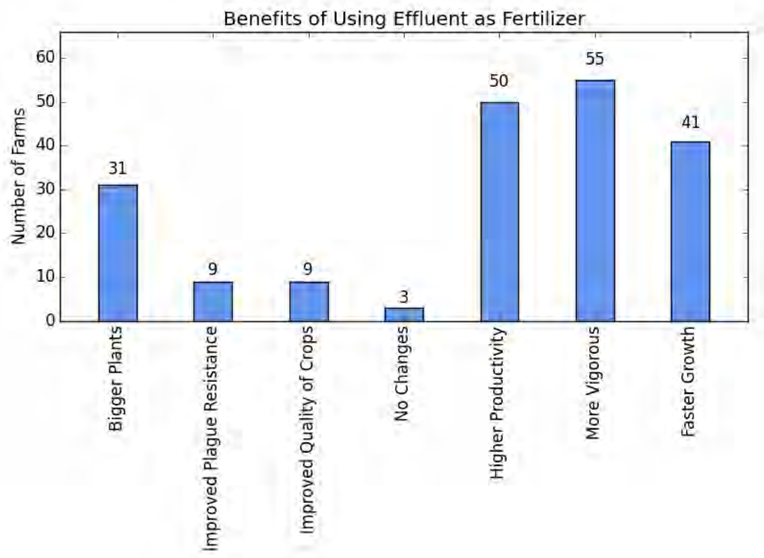

Figure 63: Most commonly reported effects of applying biodigester effluent on crops in backyard farms

The majority of users (86%) in the Industrial Sector do not use chemical fertilizers in growing their crops. However, 14% users reported to save in chemical fertilizers now that they have the biodigester effluent as a source of fertilizer. Figure 64 shows the monthly savings users obtained from substituting chemical fertilizers by the effluent of the biodigester. Users with a 2,500 m^3 system save up to $70,000 MXN on fertilizer per month, and users with a 12,000 m^3 save up to $180,000 MXN on fertilizer per month. The users that had a high dependence on chemical fertilizers are able to save a significant amount of money, while the majority who never used chemical fertilizers are able to benefit from increased productivity of their agricultural activities.

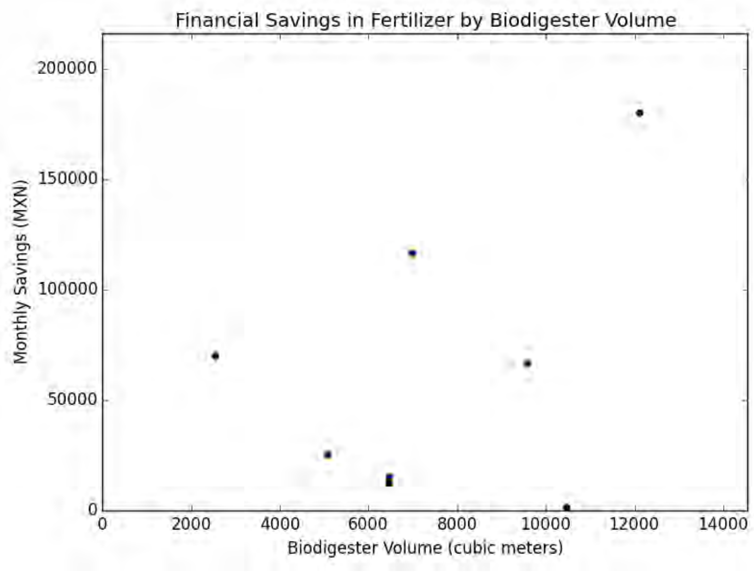

Figure 64: Fertilizer savings by biodigester volume

Benefits Summary

The digester users noted that the benefits included the following: cleaner sites, better smells, fewer insects, fertilizer savings, improved productivity of crops, fuel savings, and fewer rodents. Cleaner site was the benefit most often noted by digester users.

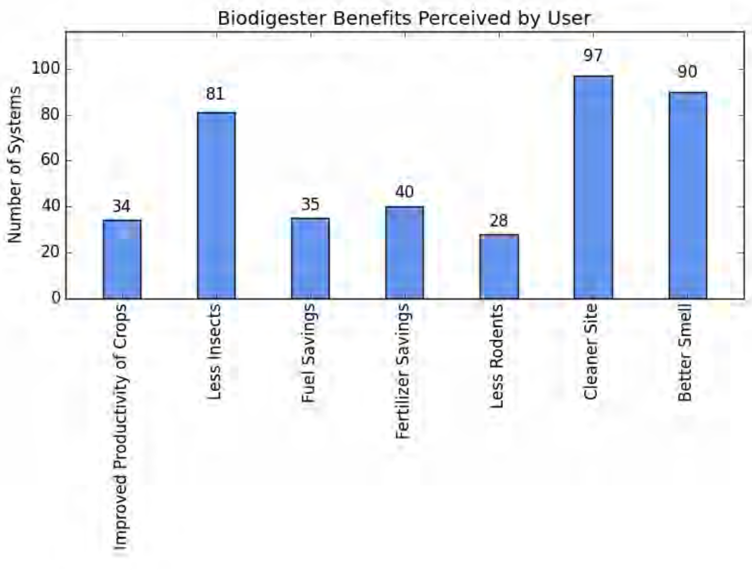

Figure 65: Mostly common perceived benefits by users

The total savings as result of the financial benefits from the biodigester are shown in Figure 66. Savings for the systems are realized as operators have less need for fertilizers and fossil fuels in the form of electricity and LPG. Users with a 1,000-10,000 m^3 system save on average $38,000 MXN per month, whereas the users with the larger system on the sector (>20,000 m^3) have no savings because they do not generate electricity nor displace fertilizer use. Users who generate electricity and displace fertilizer consumption will save more than the average, and users who only have methane burners and didn't use fertilizer in the baseline scenario will not see financial benefits from having the biodigester.

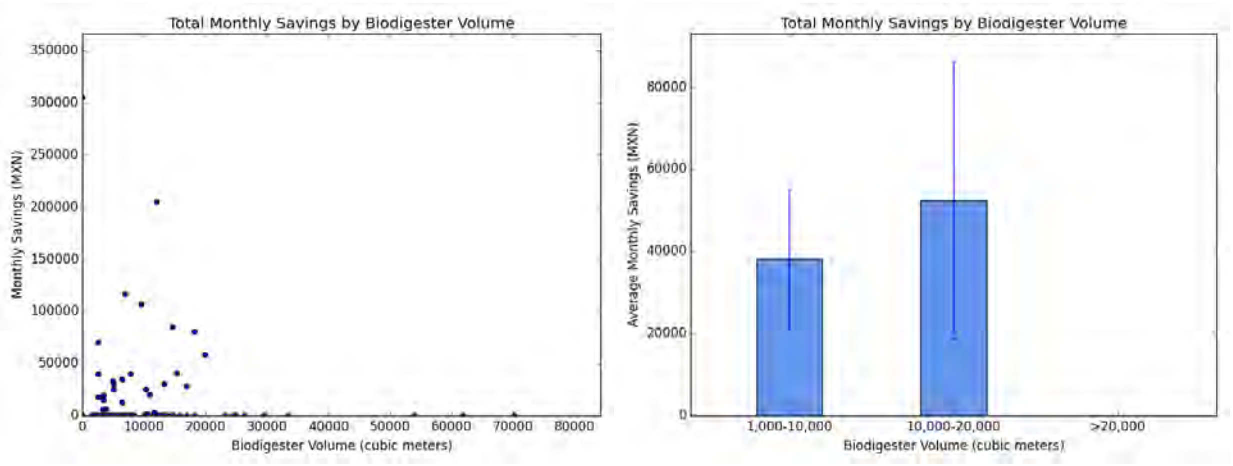

Figure 66: Total savings by biodigester volume (error bars represent 95% CI)

GHG ERs for the systems are realized as operators have less need for fossil fuels in the form of electricity and LPG, and treat their farm manure with the digester. Figure 67 shows that GHG ERs for this sector vary do not depend exclusively on system volume. The 1,000-10,000 m^3 systems produce an annual average GHG ERs of 1,360 MT of CO2e, whereas the 10,000-20,000 m^3 systems produce an annual average GHG ERs of 2,640 MT of CO2e. However the systems larger than 20,000 m^3 produce an annual average GHG ERs of 1,370 MT of CO2e, which is about the same than the 1,000-10,000 m^3 systems but much lower than the 10,000-20,000 m^3 systems. The larger systems tend to be installed on dairy farms which manure has a much lower GHG emissions potential than porcine farms that are more common in the range of the smaller systems (<20,000 m^3).

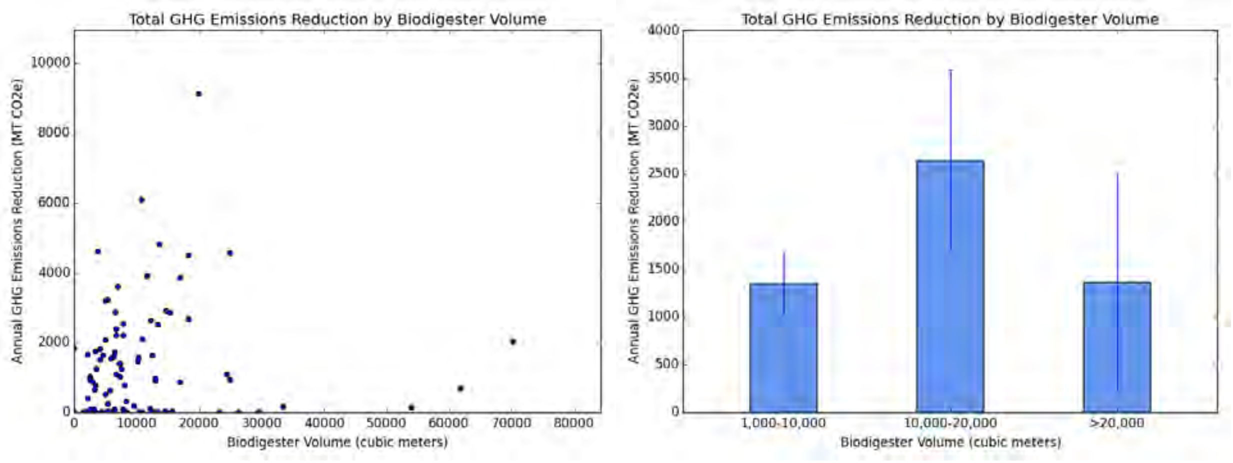

Figure 67: Total GHG emissions reduction by biodigester volume (error bars represent 95% CI)

Biodigester Impacts Across Sectors

In the following section the environmental, economic, social and climate impacts across sectors will be discussed.

Environmental Impacts Across Sectors

In addition to the aforementioned climate benefits, digesters provide significant benefits to local waterways and improve the smell of areas where they are located. In the domestic sector survey, users were able to choose among various benefits of the digester systems and ranked them in order of importance. The categories were financial savings, biogas production, manure treatment, fertilizer production, and environmental benefits. Most respondents asserted that biogas production was the most important aspect of the digester, and environmental benefits ranked as second (see Figure 68).

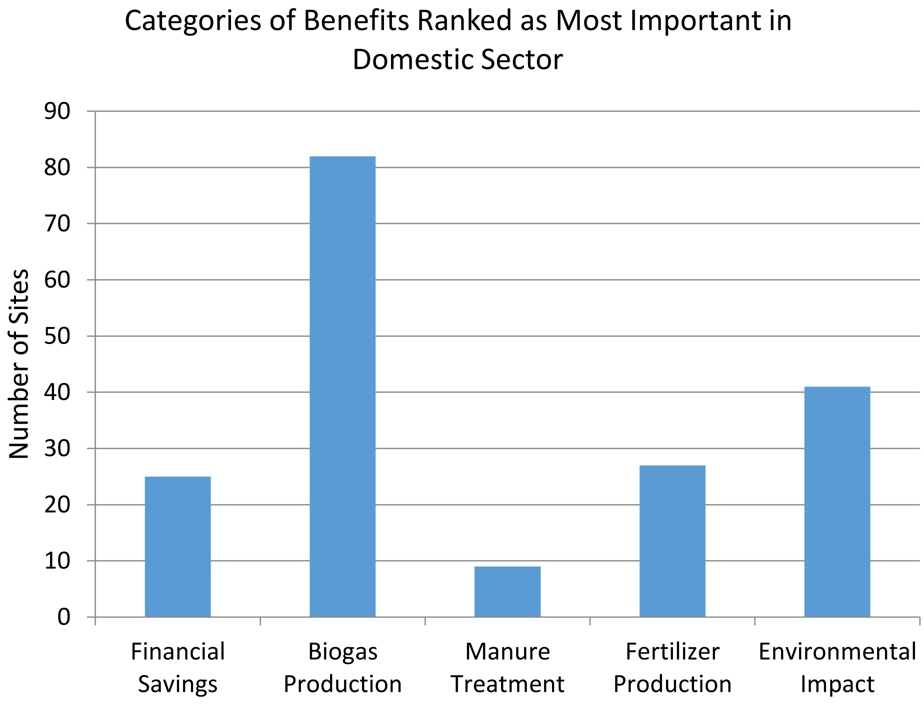

Figure 68: Categories of benefits ranked as most important in the Domestic Sector.

The environmental benefits were most likely the reduction in water contamination that resulted from having the manure treated before it was land applied and reached the river. The heat of the digester kills pathogens that can contaminate local waterways with microorganisms like giardia, E. coli, cryptosporidia, and pfiesteria (Moser, 2015). It is possible that respondents could be referring to the climate benefits of the LPG that was displaced due to the installation of the system, but this is less likely since the creation of greenhouse gases is a global problem that causes slow, incremental change that may seem less immediate in the minds of farmers.

Odor reduction could be a second environmental impact that respondents could have had in mind when they elected "environmental impacts" as their first choice for digester benefits. Anaerobic digesters do an excellent job of rendering the effluent odorless as the pathogens inside of the manure are cooked (Moser, 2015). In the productive sector, the biogas production and environmental impacts tied for the two most important benefits of the system.

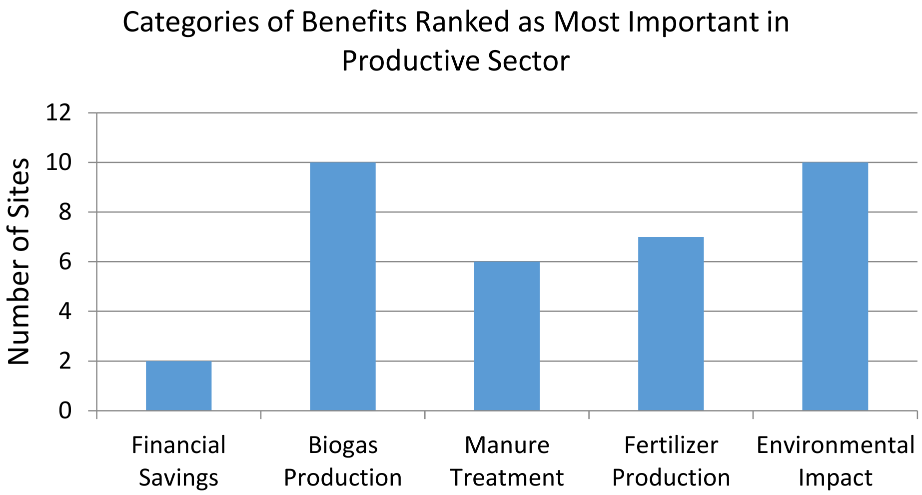

Figure 69: Categories of benefits ranked as most important in the Productive Sector.

In the industrial sector, the environmental benefits were ranked above all other benefits of the systems. This could be the case because large, industrial-sized farms are subjected to water quality fines if raw manure is disposed of in the waterways.

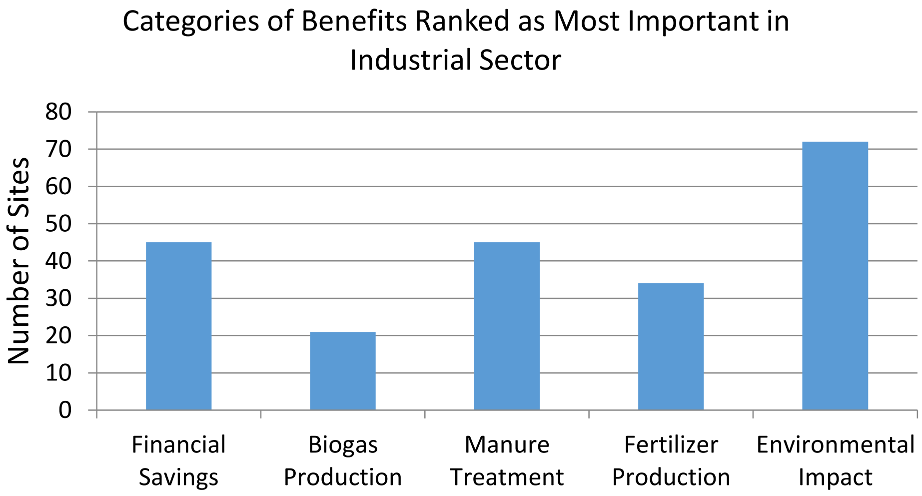

Figure 70: Categories of benefits ranked as most important in the Industrial Sector.

The farms that host domestic-sized systems do not pay water quality fines if too much manure is dumped into a local waterway. However, those systems in the productive and industrial sectors do pay fines.

Economic Impacts Across Sectors

There are three ways in which farmers save money annual when they have a digester. They pay less for energy and fertilizer, and for the industrial and productive sectors, they pay fewer fines for water quality violations as the digester creates effluent that can safely be land applied, and little fresh manure is expelled into local waterways.

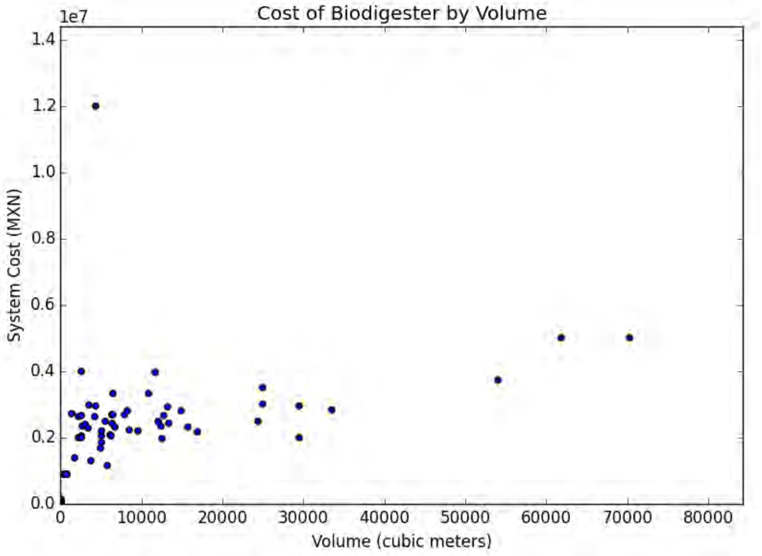

Figure 71: Cost of biodigesters by volume across all sectors.

For the domestic sector, the surveyed farms saved a total of $600 MXN/month for 10 m^3 systems. Savings scaled with system size.

In the Productive Sector, $462,000 MXN annually was saved on fertilizers on the 28 sites surveyed. Those who use the effluent for fertilizer are saving an average of $1,602 MXN pesos per hectare annually. The productive sector saved so much in fertilizers because there were enough animals to generate significant quantities of manure, and the farms were also producing crops as most of the farms raised both animals and cultivated crops.

In the industrial sector, $112, 800 MXN pesos was saved annually and $66 MXN pesos per hectare annually was saved. The amount saved per hectare was possibly so low since so many of the industrial sector farms did not use the effluent as fertilizer. These larger farms often did not have the need for it since they do not cultivate crops.

The farms that host domestic-sized systems do not pay water quality fines if too much manure is dumped into a local waterway. However, those systems in the productive and industrial sectors do pay fines. Penalties enforced by CONAGUA in Sonora are dependent on how contaminated the water is. Some farmers in the productive and industrial there have saved $3,000-4,000 MXN / month due to not paying as many fines. In other parts of Mexico, farmers are subjected to fines of up to $100,000 MXN.

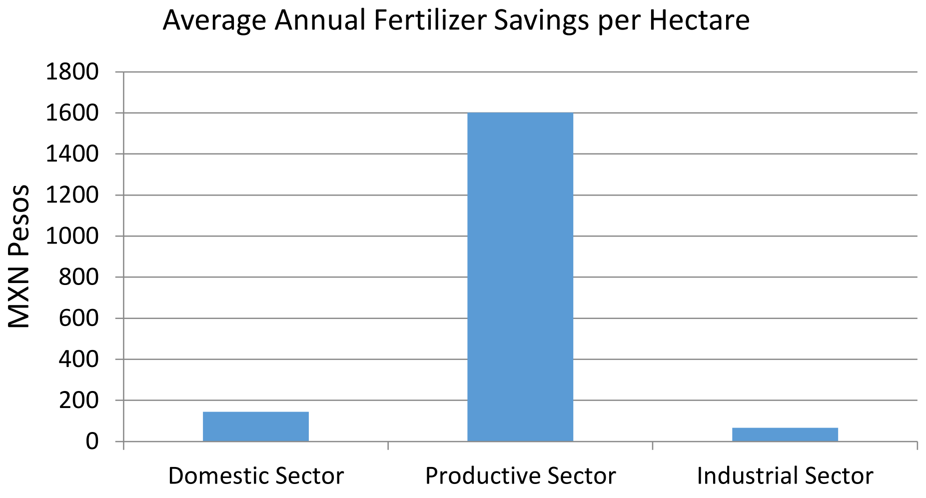

Figure 72: Average annual fertilizer savings per hectare across sectors.

Social Impacts Across Sectors

Even though there are not greenhouse gas savings from the reduction in fuelwood, there are significate societal and social benefits to the reduction of the fuelwood by each site by one half. With the digesters in place, farmers can spend less time searching for fuelwood.

The aforementioned odor reduction is another social impact that should be considered. However, this odor reduction only occurs if the digester can handle all of the manure from the farm. As farmers do not have to worry about the smell of their manure wafting towards neighbors, relationships can be improved, and the farmer benefits from not having the caustic hydrogen sulfide and ammonia, harmful fumes from the manure at his own farm. These gases are respiratory irritants. Ammonia (NH_3) can react with by-products of burning coal and other fuels and create ammonium aerosols (NH_4^+), which can travel long distances and become a regional pollutant. The volatized ammonia from the manure can also fall as precipitation and harm local waterways. Much less hydrogen sulfide (H_2S) is emitted and it is a local pollutant that does not spread widely. In small quantities, it is a severe respiratory irritant. In large quantities, hydrogen sulfide can be lethal (Powers, 2011).

Climate Impacts Across Sectors

Biodogesters provide significant climate change mitigation benefits that scale-up with volume independent of market sector (see Figure 75).

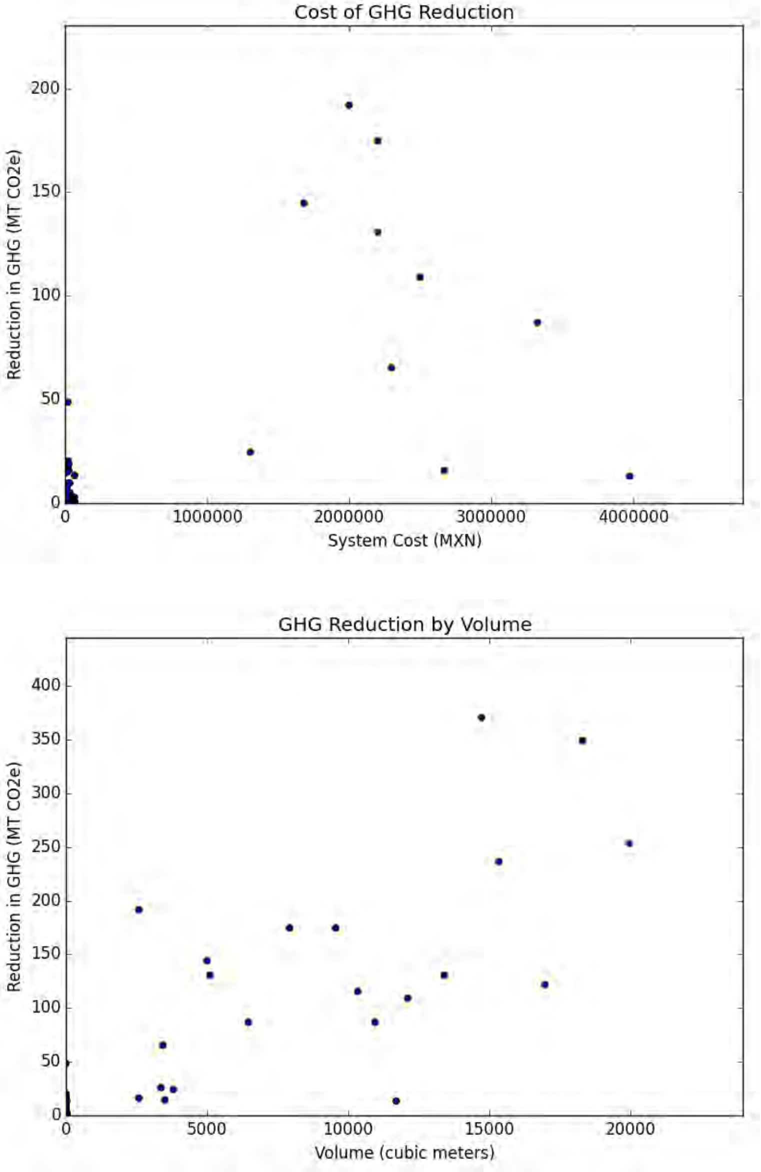

Figure 73: Biodigester cost per MT of CO2e abated across all sectors (above) and GHG emissions reductions across all sectors

Domestic Sector - Conclusions and Recommendations

Conclusion 1: Users of biodigesters in the Domestic Sector are operating their systems at less than full capacity while treating an average of 27% of the total manure that is available in backyard farms. These systems are not producing at full capacity even though the primary materials are available.

Recommendation 1: Conduct a study to determine the key barriers that backyard farmers are confronted with in regards to manure collection and management. Based on the results of the study it may be determined that these beneficiaries tend to graze animals in the field and in order to collect and process the manure upgrades to the farm would need to be implemented (e.g. corrals, feeding stations, etc.)

Recommendation 2: Provide incentives and follow up programs to encourage users to increase the amount of manure that they treat in the digester. Given that most users are utilizing the system at below full capacity

Conclusion 2: In the systems when the users are able to displace woodfuel consumption GHG emissions reductions are higher. Within the Domestic Sector the highest return on GHG ERs per program dollar invested seems to be 4 and 6 m^3 systems where the biogas displaces woodfuel consumption.

Recommendation 1: If the goal is to reduce emissions of GHGs, a program should target backyard farms where woodfuel is the primary domestic fuel supply and is harvested unsustainably (i.e. not being regenerated). Given that this demographic is highly marginalized and unable to pay for a system in most cases, it is recommended that these program be highly subsidized, perhaps greater than 90%.

Conclusion 3: Financial benefits increase significantly when users are able to displace LPG consumption and / or displace chemical fertilizers applied to their crops.

Recommendation 1: If the goal is to generate financial benefits, a program should target backyard farms that are able to displace LGP consumption and chemical fertilizer usage. Given that these systems generate significant financial benefits, the subsidy levels can be lower perhaps around 50%. However, the upfront cost, even at 50% subsidy will still be a significant barrier to this demographic. Therefore, subsidies should be combined with financing mechanisms that can reduce the upfront cost though micro-loans that will smooth out the impact that the purchase on has on the household economy.

Conclusion 4: While the large majority (89%) of the systems in the Domestic Sector are functioning well, or functioning well with minor problems, 10% of the systems are not operating because of lack of use or abandonment and 1% are not functioning because of a technical issue.

Recommendation 1: Failed systems should be targeted by a technical assistance program that will provide additional training to users on basic maintenance and repairs.

Recommendation 2: All biodigesters that are constructed of polyethylene should come with a patch kit and an instruction manual for how to repair common punctures and tears in the membrane.

Recommendation 3: If the goal is to generate the highest overall impact, including financial, social, climate and environmental impacts, a program should be targeted towards repairing the 11% of the biodigesters that are currently not functioning. With a relatively small investment in technical assistance, most of these systems can likely be recovered.

Conclusion 5: Domestic Sector biodigester are working well, are experiencing high level of acceptance within beneficiary groups, and are generating a wide range of benefits, including environmental, financial, climate, and social benefits. The impacts can be multiplied by installing more biodigesters.

Recommendation 1: Additional funding should be allocated by government programs, agencies and foundations towards Domestic Sector biodigester dissemination in order to increase the number of systems operating thereby scaling-up the benefits to society and household economies, while mitigating climate change and reducing the environmental impacts of backyard farming operations.

Productive Sector Conclusions and Recommendations

Conclusion 1: The Productive Sector has received relatively little attention by government programs when compared to the Domestic and Industrial Sectors that is backed up by the fact that the total number of systems installed in this sector is 109 compared to 799 and 1259 for the other sectors respectively.

Recommendation 1: If the goal is to generate benefits in the medium scale livestock sector, biodigester programs should be designed to target that sector.

Conclusion 2: Within the Productive Sector that includes system between 25 and 1,000 m^3 a gap exists between systems on the lower end of the distribution and systems on the higher end of the distribution. The large majority (83%) of the Productive Sector systems are less than

120 m^3 and are tubular type. Between 120 m3 and 1,000 m^3 we see a change in technology type; we see a transition towards lagoon biodigesters as we move up the scale.

Recommendation 1: Conduct a study specifically to generate information that will allow us to identity the barriers that have led to the sector to be relatively unattended.

Recommendation 2: Study the characteristics of this market sector and explore the benefits and drawbacks of applying different technology types such as tubular versus lagoon.

Conclusion 3: The systems in the higher end of the range (400 - 1,000 m^3) are underutilizing the biogas resource. In general they are simply destroying the gas through flaring and are not dedicating the gas to productive uses that could generate additional climate and financial benefits.

Recommendation 1: Resources should be dedicated to promoting complementary technologies that can take advantage of the underutilized biogas in the Productive Sector. These technologies include: biogas pumps and motors to displace gasoline consumption, and in some cases biogas generators that can displace electricity consumption through net metering contract with the local power company.

Conclusion 4: While the majority of the systems (82%) in the Productive Sector are functioning well, or functioning well with minor problems, 18% of the systems are not functioning because they had technical issue that the user was not willing or able to solve such as leaks in the geomembrane, problems with humidity and digester clogging from the lack of periodic solids removal. These simple problems can be easily solved through basic maintenance and repairs

Recommendation 1: Failed systems should be targeted by a technical assistance program that will provide additional training to users on basic maintenance and repairs.

Recommendation 2: All biodigesters that are constructed of polyethylene should come with a patch kit and an instruction manual for how to repair common punctures and tears in the membrane.

Recommendation 3: If the goal is to generate the highest overall impact, including financial, social, climate and environmental impacts, a program should be targeted towards repairing the 18% of the biodigesters that are currently not functioning in the Productive Sector. With a relatively small investment in technical assistance, most of these systems can likely be recovered.

Industrial Sector Conclusions and Recommendations

Conclusion 1: The majority of the Industrial Sector biodigesters are not operating at full capacity because they are clogged from solids that have settled and hardened in the lagoon because of lack of frequent extraction and / or lack of agitation systems.

Recommendation 1: Systems that are currently heavily clogged with settled solids that are hardened will need to be opened and cleaned out with heavy machinery (excavators and backhoes).

Recommendation 2: For new and recently reactivated installations, it is recommended to install and use agitators and remove settled solids every 3-6 months. This will avoid hardening of the solids that causes the loss of operating capacity and the need to invest in expensive maintenance processes.

Recommendation 3: Trainings, follow-up and technical assistance, particularly during the first few months of a biodigester operating, will improve the users' ability to properly operate and maintain their systems.

Conclusion 2: The majority (61%) of the Industrial Sector biodigesters are not generating the maximum financial and climate benefits because the biogas is not being put to a productive use. These systems simply destroy the methane through flaring (burning off).

Recommendation: Promoting accessory technologies that allow the end user to displace the consumption of electricity or fuels onsite in order to maximize financial and climate benefits. These accessory technologies are biogas pumps and generators, as well as generators interconnected to the grid through Net Metering contracts with the local energy company.

Conclusion 3: The success or failure of an Industrial Sector biodigester is highly dependent on the financing mechanism, and financing mechanisms that do not provide financial benefits to the end user are more likely to fail (as was the case of the Ag Cert CDM program).

Recommendation: Regardless of potential revenue streams from selling of carbon credits, programs that promote biodigesters should install systems that maximize financial benefits to the end users by providing productive uses to the biogas that displace the consumption of fuels end electricity.

Conclusion 4: There is a massive amount of CO_2e abatement being realized by the biodigesters in the Industrial Sector that is not being commercialized.

Recommendation: Investigate the potential pathways for certifying and commercializing the CO_2e offsets.

Conclusion 5: Industrial Sector biodigesters are producing an excess of effluent that is not being utilized due to lack of demand and government regulations that prohibit applying the byproduct.

Recommendation 1: Develop a market for biodigester effluent and biosolids as organic fertilizers and soil amendments

Recommendation 2: Remove legal barriers that prohibit the application of these byproducts as soil a amendment and organic fertilizer

Conclusion 6: Industrial Sector biodigesters, that are properly designed, operated and maintained, and where the biogas, effluents and solids are put to productive end uses, are generating impressive financial, social, environmental and climate benefits

Recommendation 1: Continue and provide increases in government funding to subsidize the purchase of Industrial Scale biodigesters

Recommendation 2: Target funding towards installing generators and accessories at digester sites that lack these components.

Analysis of the Effectiveness of the Clean Development Mechanism in the Industrial Sector

The CDM has two different ways of funding projects. When the Kyoto Protocol first came into force in 2005, there was just one way to register a project and earn credit for it. It was by registering the project individually or, if a collection of projects generated less than 60,000 MT of CO2e in reductions or 15 MW capacity of power, they could be bundled and registered as one project. In 2009, the United Nations Framework Convention on Climate Change (UNFCCC) approved a new Programme of Activities (PoA) that was meant to help small-scale projects overcome the cumbersome paperwork requirements necessary to earn CDM credit. The template for PoAs was revised to make it easier to submit PoAs and by the end of this year, 40 were submitted to the UNFCCC's Executive Board (South Pole Carbon). A PoA consists of a document that provides guidance on how emission reductions can be earned from a particular activity like planting trees or replacing incandescent light bulbs with compact fluorescent bulbs in an urban environment. This PoA document also provides the structure for how projects are deemed eligible, how they operate, and how they are monitored and credited. Often PoAs are written to achieve a particular policy goal of reducing emissions or implementing a new technology and must have a specific coordinating entity that develops or helps develop the project (CDM Rulebook).

Component Project Activities (CPAs) are individual measures (or a set of inter-related measures) that comply with the rules set up by an individual PoA. These projects (unlike CDM projects) can be added at any time under a PoA. Therefore, if projects are not implemented simultaneously (as is required for CDM projects that are bundled together), they may still qualify under a PoA (CDM Rulebook). Because the PoA portion of the CMD did not come into force until 2009, many of Mexico's early digester projects under the CDM were registered individually. Currently, Mexico has four methane destruction from manure PoAs, and one CPA developed under each of them. Typically different PoAs had to be created for similar types of projects, e.g. digesters, because each PoA is specific to the coordinating entity involved. For example, Islan Group is listed as the coordinating entity for one of the PoAs, and projects that attempt to qualify for that PoA must also be developed by Islan Group. Other PoAs specify the exact type of technology that must be used in order for the PoA to qualify. Because these PoAs began between 2011 and 2013, there are not yet any data on the issuance success of these projects. However, it should be noted that none of them have failed validation, registration, or verification yet. The future will prove whether or not these PoAs, which can benefit from less transaction costs as many projects created over time can qualify under a CPA and be lumped together for auditing purposes, will be more successful than the individually-registered projects or those that are bundled together as they have similar start times. In order for projects to earn credit through the CDM, they must be audited annually and be producing the expected greenhouse gas reductions either through flaring methane or using it for heat or electricity. Certified Emission Reductions are awarded on a carbon dioxide equivalence basis for the actual greenhouse gas reductions made in a year. Flow meters that record gas flow and sensors that record temperature on flares take measurements every 15 minutes, which allows auditors, called Designated Operational Entities (DOEs), to ensure that credits are only awarded when gas is flowing and being combusted. Alternatively, heat or electricity can be made with the gas, and electricity records and furnace temperatures are used to corroborate the gas destruction (UNFCC, 2009).

Global Comparison

The CDM Pipeline, which is maintained by the United Nations Environment Programme (UNEP), analyses the number of CDM projects in the process of being validated, registered, and verified. As of January 1, 2015, there were 411 methane avoidance projects from manure worldwide that had attempted registration or were in the pipeline to be reviewed for acceptance. Of these 411 projects, 143 were withdrawn or rejected by DOEs and the UNFCCC Executive Board. This means that the worldwide failure rate of these projects is 55% (Figure 74), and there are just 268 of these projects in operation or in the pipeline worldwide. Mexico has attempted 159 of these methane avoidance through manure systems, and 59 have failed. Therefore Mexico's failure rate for these projects is 37% (Fennman, 2015).

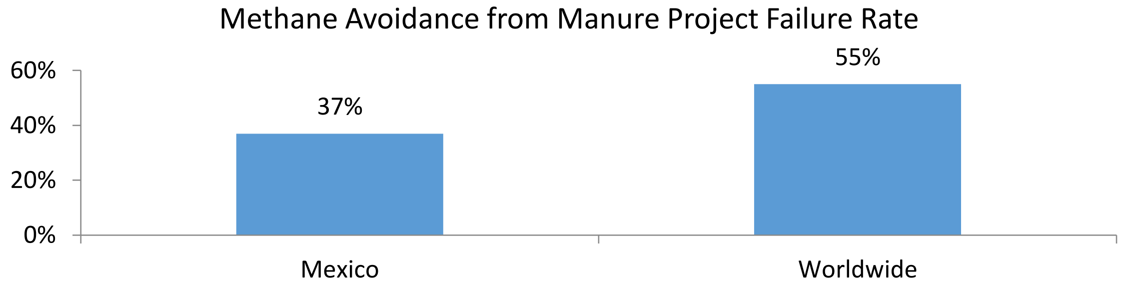

Figure 74: Methane avoidance from manure project failure rate.

Given the fact that Mexico hosts 37% of the world's methane avoidance from manure projects (Figure 75), shedding light on why these projects have not succeeded in Mexico could have global significance as Mexico has been somewhat of a test laboratory for these projects over the last 10 years (Fennman, 2015).

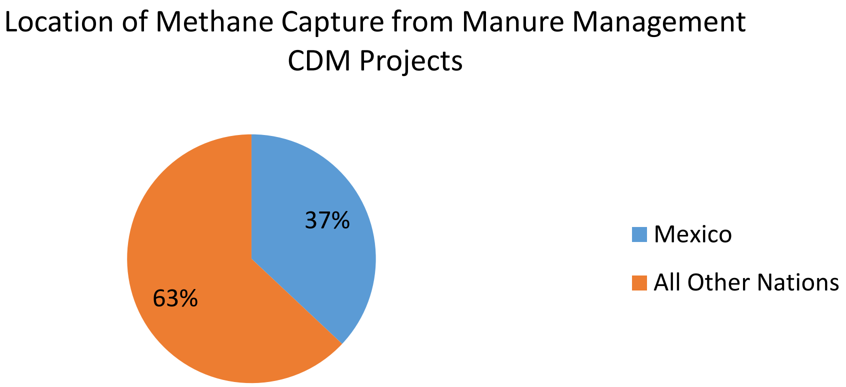

Figure 75: Location of methane capture from manure management CDM projects.

Project Failure by PDD Consultant

When analyzing why 59 of the 159 attempted anaerobic digesters failed, the most striking similarity in many of the failed projects is the Project Design Document (PDD) consultant (Figure 76). The PDD consultant is responsible for writing the initial document that establishes why the project should qualify for CERs, and often this consultant will shepherd the project through the tedious and long paperwork process to be validated, registered, verified, and eventually earn money for these CERs. Some PDD consultant companies will even take an equity state in the project in question and receive their payment for the services in the form of a percentage of the CERs generated. Three main PDD consultant companies operate in the methane destruction from manure projects in Mexico; these companies include Ag Cert with an attempted 111 projects, Ecosecurities with an attempted 30 projects, and MGM with an attempted 7 projects. Ten other PDD consultants have worked in the country, but none of these consultants have worked on more than two projects. Therefore, the analysis that follows will focus on the projects developed by Ag Cert, Ecosecurities, and MGM.

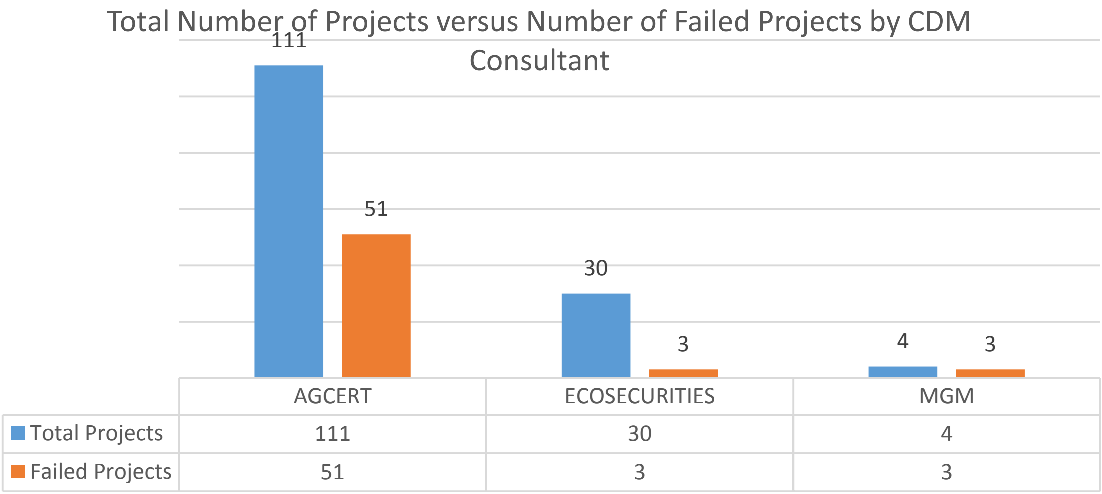

Figure 76: Total number of projects versus number of failed projects by CDM consultant.

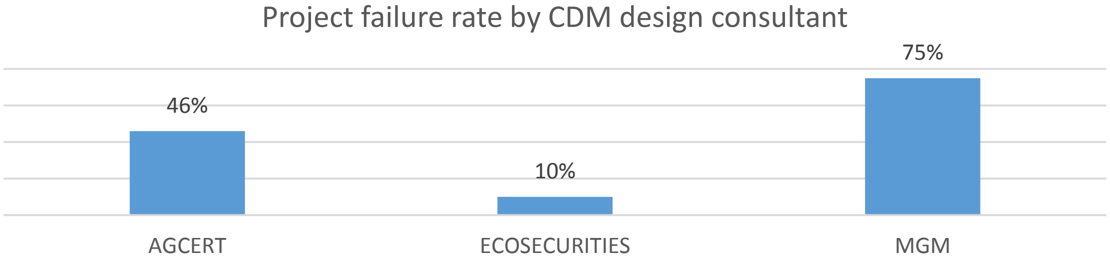

Figure 77: Project failure rate by CDM design consultant.

Ag Cert

Ag Cert was the PDD consultant for majority of the projects attempted (Figure 77), and also has the highest failure rate, defined as projects that are listed on the UNFCCC webpage as being rejected, withdrawn, or validation stopped (Fennman, 2015).[12] Part of this failure can be attributed to Ag Cert's model, which was to take a large equity stake in projects and earn, in some cases, 90% of the resulting CERs in return for providing the capital and expertise to build the digester (Lokey 2009). However, when the price of carbon bottomed out and carbon credits became almost worthless at $6.57 USD in 2013 (Bloomberg Business), Ag Cert dissolved and found that it was no longer in its interest to maintain the existing digester projects. These digesters need periodic maintenance and supervision by engineers as portions can become clogged, ignition lights can be severed, and water can accumulate on the top and lower the digester's temperature unless pumps promptly remove the water from the top. Also, there needs to be close coordination between farm operators, veterinarians, and digester engineers as antibiotics or feed with the wrong pH can impact the proper functioning of the microorganisms in the digester that break down the manure into methane (Lokey, The Status and Future of Methane Destruction Projects in Mexico, 2009). Due to the abandonment of these systems, farmers were left to fend for themselves, and in some cases even cut the digesters' top plastic lining to relieve the gas pressure when the system became clogged. In these cases, projects failed annual verifications and were no longer awarded CERs.

For the Ag Cert project 1561 in Chihuahua, which was withdrawn, the UNFCCC registration request form lists the following problems with the project:

"1. Minor issue: The IPCC value for the methane conversion factor (MCF), should be stated in table B.2 of the PDD.
2. Minor issue: Further clarification is required to explain the percentage discounted from the total emission reductions (PDD, Table B.6, p13) that may be lost due to volatile solids reduction ("CDM project activity registration review form (F-CDM-RR")."

These problems seem easily rectifiable, but perhaps were not resolved due to the aforementioned drop in carbon prices which led to Ag Cert dissolving and not following through with the maintenance of their projects. No other methane avoidance from manure projects in Mexico have

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[12] It should be noted that there are 10 other PDD consultants that each have one project in Mexico. Due to the low volume of projects for these PDD consultants, they are not shown in the chart above.

a UNFCCC paperwork trail that can be followed to explain the reasons for their failure to create CERs.

The UNEP's CDM Pipeline ranks PDD consultants based on how many successes and failures they have had. Ag Cert has 146 projects worldwide; 145 of them are methane avoidance from manure projects. Forty-eight of Ag Cert's projects had validation (the process by which the project is deemed eligible to begin creating CERs) terminated, which makes it the PDD consultant with the second highest number of terminated validations (after Ecosecurities with 60) in the world. A total of 2,051 PDD consultants were included in this analysis (Fennman, 2015).

Of the CERs expected from the existing methane avoidance from manure projects in Mexico, an average of 39% of these CERs have actually been delivered (known as issuance success), hinting at major technical problems with the operating digesters (Fennman, 2015). The only PDD consultant that has had CERs verified from projects is Ag Cert. So, while many of Ag Cert's projects have failed, at least some are producing (or have produced) CERs. Other PDD consultants like MGM and Ecosecurities who have multiple projects in Mexico have had no verified CERs from their projects. Many of these projects were developed as long ago at 2006 and while monitoring reports were created that claimed the emission reductions of thousands of tons of carbon dioxide equivalence (over 17,000 for a two year period for one project), no CERs were ever issued and in June of 2014, the verification contract was discontinued and the project proponent, which was Ecosecurities, chose to discontinue verification (Ecosecurities). There was no explanation in the public documents posted by the UNFCCC as to why this project failed to generate CERs. And, the other Ecosecurities projects did not even have monitoring reports created for them.

Ecosecurities

The 30 Ecosecurities projects in Mexico were distinct, but 29 of them were owned by one family-run business called Granjas Carroll Mexico (GCM). In the project documents for GCM 23, a concern was raised that these projects were essentially a debundled project, which would disqualify it. Other issues such as the exact efficiency of the flare and the exact capacity of the project's electrical generation were also questioned by the Executive Board of the UNFCCC. It is possibly these concerns that led to the projects never earning CERs ("Response to Request for Review"). While all these projects have not been officially withdrawn, they probably will not ever generate CERs since they are all similar projects in close proximity to each other and they have been operating since 2006 and 2007 and not yet received any credits. Therefore, if these project failures are counted, Ecosecurities has a project failure rate of 100% and surpasses Ag Cert.

Other reasons for the Ecosecurities GCM projects' failure could include climate and coordination with a foreign project developer. The digesters were located at a high elevation in Puebla, Mexico and struggled to maintain the requisite temperature for digester functioning as will be mentioned later in this paper. The covered lagoon-style digester did not have insulation that prevented it from losing heat, and a more insulated, Scandinavian design that used a heating system to keep the contents of the digester at 38°C would have been preferable. Also, the project was first developed by UEM Group Berhad, a Kuala Lumpur-based company, used sophisticated technology that replicated a design used on dairy cows. The tubes used have a diameter that is larger than needed and better suited for cows instead of pigs. The mechanical devices used to tighten the plastic cover are susceptible to tear. The open flare for the system worked for 24 hours before it burnt the pilot light cables and threatened power lines that were sited too close to the flare. Since UEM is based abroad, they did not have an engineer that could frequent the project and offer technical assistance. As a result of this experience, GCM hired the locally-based and more economical Geosistemas to handle the rest of their digester development (Lokey, The Status and Future of Methane Destruction Projects in Mexico, 2009).

MGM

MGM's projects were finished between 2012 and 2013 and some have not yet submitted verification reports. Therefore, it is impossible to tell from the UNFCCC paperwork trail why three of the seven MGM projects failed. While 10 other PDD consultants have submitted projects, as previously mentioned, none have more than two projects, so trends would be impossible to extrapolate.

Geographical Analysis

Beyond the PDD consultant chosen, another possible explanation for the success or failure of a project is its location (Figure 78). Digesters that are located in cool climates can fail to keep the manure at the ~40°C that is necessary to maintain the health of the microorganisms that break down the manure. Hog farms at high altitudes in Mexico have had difficulty maintaining a constant temperature. To remediate this problem, operators of some hog farms at high altitude in Perote, Mexico considered heating the contents of the biodigester with the excess heat from a microturbine that would burn methane from the digester. If digesters are located in a State with frequent rains, the digester can become too cool as pools of water gather on the surface of these positive pressure digesters and deflate the methane bubble on the surface of the excrement. The pool of water on top lowers the temperature of the excrement. Some Ag Cert projects in the State of Veracruz had issues with pooling of water on their digesters because of the frequent storms in the rainy season. If the project has no full-time grounds keeper and relies on weekly visits from an engineer that services a large territory, or in the case of Ag Cert where no engineer services the digesters anymore, there is sometimes not a pump on site to move the water off the top of the digester surface in a timely manner (Lokey, 2009).

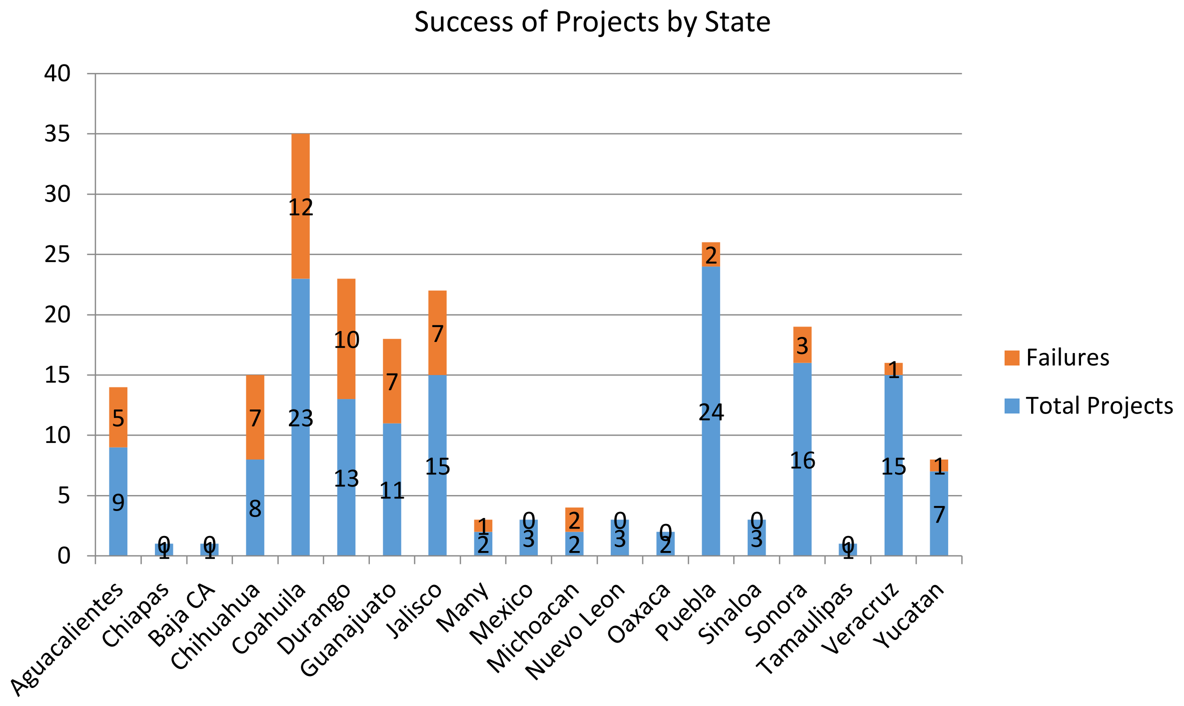

Figure 78: Success of projects by state.

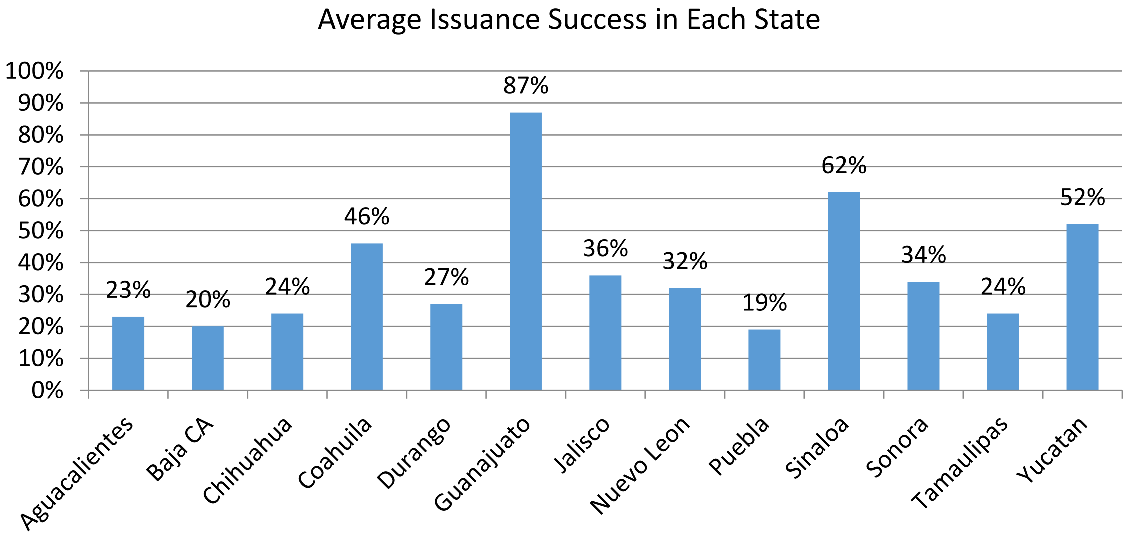

Figure 79: Average issuance success in each state.

For the two graphs above (Figure 78 & Figure 79), if a project was listed as being in multiple states, the first state listed was chosen for purposes of this analysis. The "Average Issuance Success in Each State" graph does not include all states included in the preceding graph because the data are not available for all states.

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Appendices

Case Studies

In this section, four Industrial Sector case studies are presented. These case studies present examples of successes and failures in the Industrial Sector.

Case Study 1

Farm Type: Swine	*Biodigester*	*Electricity Production*
Animal Population: 12,500	*Size:* 100x50x6m	*Brand:* 2 x MOPESA Generators
Site Weather: Hot	*Cost to Owner:* $0 MXN	*Op. Capacity:* 2 x 40 kW

The biodigester was installed in June, 2004 by Ag Cert. In 2005 the owner installed 2 generators without government subsidy for a total investment of $600,000 MXN. However, the generators never operated for more than 10 consecutive days, before they had to stop for maintenance or repair. In a 2 year period, the savings from electricity didn’t surpassed the $5,000 MXN mark. The operational cost of the generators was about $4,500 MXN, which translates into a net monthly savings of $500 MXN for a $600,000 MXN investment. When a major repair was due after 2 years of operation, the owner decided to abandon the equipment. After Ag Cert stopped operations in 2012, the biodigester represents a $6,200 MXN monthly expense due to the high level of solids in the reactor that need to be partially extracted every 6 months in order to allow the biodigester to decompose the manure.

Case Study 2

Farm Type: Swine	*Biodigester*	*Electricity Production*
Animal Population: 8,500	*Size:* 81x40x6m	*Brand:* Caterpillar Generator
Site Weather: Hot	*Cost to Owner:* $0 MXN	*Op. Capacity:* 75 kW

The biodigester was installed in May, 2009 by Ag Cert. That same year the owner installed a generator without government subsidy for a total investment of $900,000 MXN. The monthly savings from electricity have averaged $85,000 MXN. The operational cost of the motor-generators is about $16,000 MXN, which translates into a net monthly savings of $74,000 MXN and a return on investment period of one year. After Ag Cert stopped operations in 2012, the owner was well motivated to take over the operations of the biodigester, and due to good practices the biodigester has not represented a significant cost for the farm.

Case Study 3

Farm Type: Swine	*Biodigester*	*Electricity Production*
Animal Population: 8,500	*Size:* 6,676 m^3	*Brand:* NA
Site Weather: Hot	*Cost to Owner:* $1,000,000 MXN	*Op. Capacity:* NA

The biodigester was installed in May, 2013 by the farm with half of the cost subsidized by a government program. The one million pesos investment by the owner was done with the hopes to profit from the sale of carbon credits. However, the owner couldn't find a market for the methane capture from the biodigester. The incentive to make an additional investment in order to generate electricity from biogas is high but the capital available to the farmer for investment is low. For this reason, the owner is looking for a government subsidized generator in order to start seeing a return on this investment.

Case Study 4

Farm Type: Swine	*Biodigester*	*Electricity Production*
Animal Population: 15,500	*Size:* 11,668 m^3	*Brand:* MOGEMEX
Site Weather: Hot	*Cost to Owner:* $3,226,000 MXN	*Op. Capacity:* 150 kW

The biodigester was installed in June, 2013 by the farm with only 20% of the cost subsidized by a government program. Along with the biodigester, a 65 kW (nomical capacity) generator was installed without government subsidy for a $300,000 MXN investment for the generator. The generator stopped producing electricity very frequently due to a diverse set of issues. After two years, the farm stopped the generator, and replaced it with a 150 kW (operating capacity). The new generator had a total cost of $1,320,660 MXN ($820,660 farm and $500,000 government subsidy). The monthly savings from electricity have not surpassed the $4,000 MXN mark because the generator stops working due frequent to technical problems. The monthly operational cost of the motor-generator is about $3,500 MXN, which translates into net monthly savings of only $500 MXN. Under the current situation, the farm has spent over $5.3 million MXN in an investment that only saves $500 MXN per month. Under an ideal scenario the farm should be saving over $100,000 MXN per month, but they haven't managed to properly operate the system, and as a consequence are losing a substantial amount of money.

Summary of Study by FIRCO and SAGARPA, "General Diagnostic of the Current Situation of Biodigester Systems in Mexico"

This appendix of the report is dedicated to translating and summarizing a study conducted in 2009 by FIRCO and SAGARPA with the objective of assessing the type and health of the existing digesters in Mexico. The study entailed 345 digester site visits where surveys and tours of the projects were undertaken to understand the digester's functioning. Of these sites visited, 268 were digesters that were either registered under or attempting registration under the CDM, and 77 others were sponsored by a government; 73 by FIRCO and 4 by EPA's Methane to Markets (Figure 80).

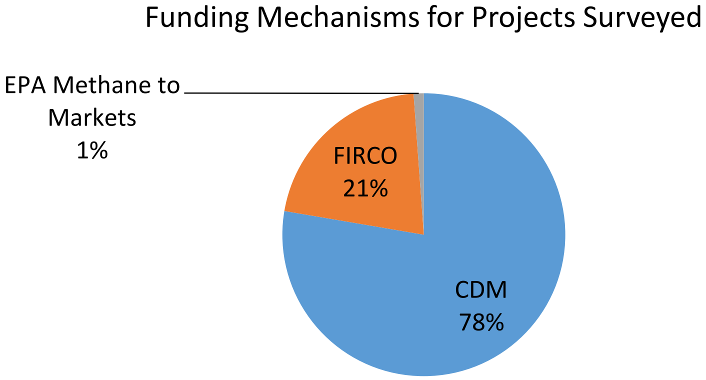

Figure 80: Funding mechanisms for projects surveyed

The report concluded that overall, 47% of digesters (188 of those surveyed) were not designed correctly and/or were not functioning correctly. Sixteen percent are not using the secondary lagoon (for effluent from the digester), leading to increased contamination of local waterways. On the other hand they found that most digester operators considered the reduction in the contamination of water from their effluent to be the best benefit of the systems. This was also found to be the case with most of the CDM projects; in only 10% of the CDM projects did the project owner say that the economic benefit of the CERs was the driving force behind the project.

Of the 333 biodigesters that were found to have a flare for biogas, only 121 were successfully measuring the biogas flow to the flare and burning the methane, which is required for creation of CERs under the CDM. In a sample of 145 digesters, only 65% of the expected biogas (as calculated by CDM methodology “Approved consolidated baseline methodology ACM0010”) was being produced. The major cause of this underproduction of gas was due to the farms having less animals than they originally expected to have. The report concluded that if one takes into account the actual animal population currently on the farms, the actual gas production is 85% of the expected total.

Design Considerations

The report concluded that the major reason for the low gas production includes design considerations of the digester, proper maintenance of the system, and failure of the equipment (Figure 81). The major cause of low biogas production was the oversizing of systems; of the 345 operating digesters, 205 were poorly-sized. They reported that the second most common problem with the digesters surveyed was the absence of an agitation system, which stirs up the manure, ensuring that it stays at a constant temperature and that the microorganisms are spread throughout the digester. Of the 345 digesters sampled, 104 lacked these agitation systems.

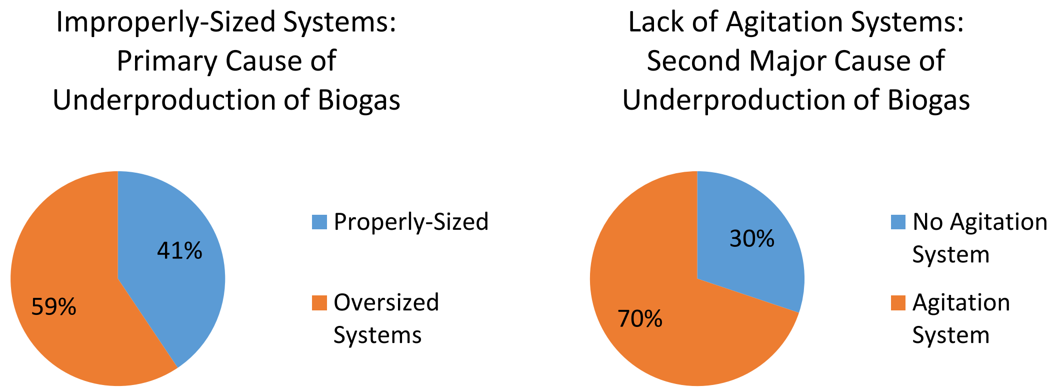

Figure 81: Main causes of biogas underproduction.

Poor System Maintenance

The FIRCO study discovered that apart from the design issues that lowered biogas production, system maintenance challenges also resulted in less biogas being produced than expected. Many owners reported not being familiar with the digester functioning, which led to systems being abandoned and other systems lacking the preventative and corrective maintenance necessary. Typically, each farm reported having one person in charge of the digester, but this person is usually a regular farm worker who is assigned to review the system periodically. However, this person is often not educated in the type of maintenance required by each component of the system or the frequency with which each part should be maintained. It was found that the inside of many biodigesters had not only a mixture of excrement and water, but in some farms also had trash, plastic bags, withered leaves, and other things that can clog the system. In some of the hog farms where the diet of the pigs included green fiber, the fiber clogged the pipes and inhibited the functioning of the digester. A failure of equipment created clogs in some influent pipes, accumulation of solids in the primary part of the digester, and in some occasions a complete collapse of the system. Other problems attributable to digester maintenance were the use of antibiotics in animal feed (which killed microorganisms in the digester that break down the manure into methane), low digester temperatures due to water and mud (occasionally from landslides) accumulating on the top of the digester, and the lack of a chemical analysis on the digester to be sure that the pH and other specifics of the manure are appropriate for the production of methane.

System operators also often surpassed ideal water to manure ratios in the digesters by over-diluting the manure put into the systems. The ratio should between 3:1 and 9:1 water to excrement. However, many systems had ratios of water to excrement that were higher than the 9:1 maximum. Also, these systems had a long retention time of 60 days.

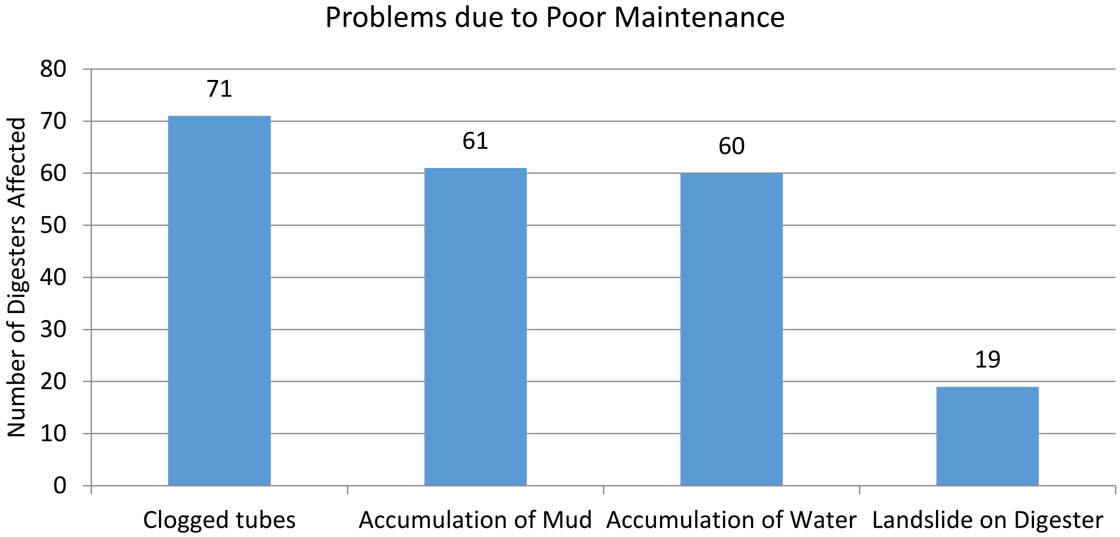

Figure 82: Problems due to poor maintenance found in the FIRCO 2009 Report.

Equipment Failure

The third most common reason for low biogas production and system failure was found to be from equipment failure. Of the 345 digesters surveyed, 164 digesters had an equipment failure. The most common types of equipment failures were in the following systems: agitation systems, biogas meters, sulfur meters, generators, and flares. In the agitation systems, only 3% malfunctioned, and this was due to a buildup of solids that should have been removed. Of the biogas meters, 19% failed to correctly record when biogas was flowing. Only 30 systems surveyed had sulfur meters, and 10% of the sulfur meters surveyed had problems. Usually these failures were due to the fact that they had not been replaced twice a year as called for by the manufacturer. Forty percent of the generators installed failed, and these failures were generally due to a lack of maintenance. Of the 333 flares installed, 290 were working, but of these working flares, 26% had reported problems due to the pilot light going out, the flare extinguishing, material supporting deteriorating, and poor combustion.

Gas leaks can occur in the tubing, the cover, and the anchoring of the cover of digesters. Of the total digesters surveyed by FIRCO, 254 had leaks. Most leaks were in the geomembrane due to scraps on the outside or poorly-thermofused material. Eighty-eight of the surveyed systems had leaks in tubing that was not sealed well or had not been maintained. There were also 27 cases of leaks in the anchors of the tubing, and 34 cases of leaks in the tubing to the flare. The least number of cases of fugitive emissions were in the anchoring of the geomembrane.

Summary of Digester Problems

Of the total 159 problems detected by the FIRCO researchers, 100 resulted from less gas being generated than expected. Of those 100, 35 projects had the absence of an agitation system, 37 projects had poor maintenance, and 28 projects had equipment failures. The absence of an agitation system represented 46% of the problems detected in 145 digesters, which indicates that there was a problem with the initial design of these digesters. The oversizing of digesters also indicates that more communication between the system designer and operator/owner should occur.

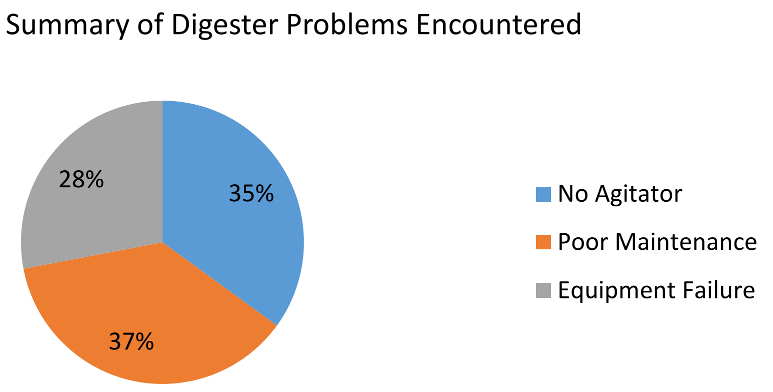

Figure 83: Summary of Digester Problems Encountered

Future Prospects for Digesters in Mexico

Several consultants including Ag Cert, Ecosecurities, Cantor CO2, Grupo Porcícola Méxicano, and others have had the intent of registering 563 biodigester projects in hog farms and dairies in Mexico. However, only 258 digesters have been built. The remainder of the digesters (surveyed in this study) were constructed or are in the process of being constructed with the support of FIRCO or the EPA Methane to Markets Initiative.

The most profitable digester systems are those with more than 500 animals. It is usually easy to establish a baseline in these systems from the secondary lagoon. In general, the hog farms tend to be more profitable. Right now most dairies have dirt floors, which affects the collection of manure and introduces impurities into the digester that reduces its ability to create methane. There is enormous potential in the hog industry in Mexico. Ninety percent of hog farms could implement this technology while 95% of dairy farms could (FIRCO & SAGARPA, 2009).

Recommendations for the Future (FIRCO & SAGARPA, 2009)

The following recommendations were given in the report in an effort to improve the performance of digesters and help avoid the abandonment of existing digesters.

1. *Implement a rescue program of those digesters that were installed and abandoned at various stages of development by developers.*
2. *Ensure that the companies installing the digesters include the owners or those who will be operating the systems in the design conversation. Doing so will help the digester be better sized for the number of expected animals, and ensure that the operators use the proper ratio of water to manure, avoid clogged pipes due to improper animal feed, and avoid the overuse of antibiotics that compromise the digester's functioning.*
3. *Hold a series of workshops in the hog farm and dairy regions that showcase the potential of the technology to reduce water contamination, improve the sanitation of the animal operations, and provide a positive economic benefit.*
4. *Extend the scope of this diagnostic into a second stage that would include all of the documented digesters. This study would be more widespread and be able to better identify the pitfalls and opportunities of this technology.*

5. *Help support new technologies, specifically those bag systems for medium-sized (51-500 animals) and smaller-sized farms (1-50 animals), that may use biogas for thermal energy in applications such as home kitchens for cooking.*