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Renewable energy potential in the Usumacinta watershed: Status and opportunities

PAMPILLÓN-GONZÁLEZ Liliana†, SARRACINO-MARTÍNEZ Omar, HERNÁNDEZ-GÁLVEZ Geovanni, ORDAZ-FLORES Alejandro*.

Universidad Juárez Autónoma de Tabasco.División Académica de Ciencias Biológicas. Carretera Villahermosa-Cárdenas Km. 0.5, 86100, México
Universidad Iberoamericana, Departamento de Física y Matemáticas, Prolongación Paseo de Reforma 880, Lomas de Santa Fe, México, C.P. 01219, Ciudad de México

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Abstract

Watersheds stand out for their rich ecosystem resources and biodiversity. In Mexico, the Usumacinta watershed leads the country's last living river, habitat of endangered species and with a high diversity of endemic aquatic species. Over recent years, it has been affected by human activities. This situation emphasizes the need to meet global energy demands through a model of sustainable development. In this context, this paper addresses a first study of the status and opportunities to use renewable energy resources in the Usumacinta watershed. Biogas and solar energy potentials were determined through data analysis, on site visits, field data collection and energy potential estimations. The biogas potential (124 TJ/y) is related to the livestock production systems established (90% extensive systems). Moreover, the region is located in areas characterized for being susceptible of flooding, high water table, salinity and sandy texture in plain. The solar potential shows a daily average solar radiation of 4.64 kWh/m^2/d that is favorable for low and medium temperature thermal technology throughout the year. Exploiting these potential could power 66, 244 households, avoiding the emission of 63,042 tons of CO_2e in a region where the lack of electricity still persists.

Biogas, Clean Technologies, Solar Thermal, Sustainability, Vulnerability

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*Correspondence to Autor (E-mail: alejandro.ordaz@ibero.mx)
† Researcher contributing as first author.

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1. Introduction

Watersheds stand out for their rich resources and biodiversity. They are more than the sum of patches of land and streams of water (Johnson et al., 2001). Watersheds involve the interaction among species, communities, ecosystems, but also the sharing of direct and indirect ecosystem services and resources like water, forest, springs, storage of organic matter, landscape, among others. Mexico gathers around 393 watersheds (Cotler et al., 2010).

Half of the watersheds in Mexico present from very high to extreme deterioration degree, or from low to high-pressure level of alteration (Cotler et al., 2010); and there is consider that 75% of the Mexican population is distributed along 13 watersheds. The Grijalva-Usumacinta watershed corresponds to these characteristics.

The Usumacinta watershed, located at the south of Mexico, is the ecosystem of numerous species, habitat of waterfowl populations (Ogden et al., 1988), den of threatened and endangered species (Primack et al., 1998). It is also the path of Mexico's mightiest river, "the Usumacinta" that, along with its tributaries, gives life to an impressive hydrological network.

Because of the wealth of natural resources, over recent years the Usumacinta watershed has suffered the developing human activities: extension of roads, colonization and expansion of agricultural land, and changes in land use (Manjarrez-Muñoz et al., 2007) to exploit energy and resources. The impact of these activities has yielded the decline of the forest in the region (Tudela, 1992), eutrophication and hypoxia in water bodies (Rabalais, 2004), among other consequences. Additionally, lack of access to energy services is a serious hindrance to economic and social development and must be overcome, as stated in the UN Millennium Development Goals.

The municipalities of the Usumacinta watershed are also characterized by having for the highest poverty levels in Tabasco. Major gaps exist in access to social security and basic services in housing, exceeding state and national averages. Vulnerability in these regions tends to increase due to poverty, lack of energy and weakness of local governments.

This starling situation has encouraged the need to meet global energy demands through a model of sustainable development, mainly in a state like Tabasco, in which the role of renewable energy is still limited, shadowed mainly by oil industries. In this context, the objective of this paper is to address a preliminary study of the status and opportunities on the use of renewable energy resources in the portion of the Usumacinta watershed that lies in the boundaries of the state of Tabasco, Mexico.

There are a few studies on energy vulnerability in Tabasco. In this regard, this article tries to start an investigation, finding the first answers and establishing further question for a state where 28.5% of the population live in alimentary poverty, in a country with only 43 researchers per million people (Laclete, 2012).

Understanding the renewable energy potentials and energy uses in the Usumacinta watershed will be useful as a complementary strategy to link the utilization and conservation of resources; particularly, in the establishment of an adequate management model that promotes renewable energy technology adoption, reduction of social inequalities, increased production, and redefinition of power structures (Lillo et al., 2015). Moreover, the use of renewable energy technologies, clean technologies and energy efficiency are considered promising alternatives to countries like Mexico that run large efforts to promote a sustainable development.

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2. Methodology

2.1 Study area

The study area corresponds to the terrestrial portion of the lower Usumacinta watershed located in the southeast of Mexico in the state of Tabasco, which is bordered to the south and east by the Republic of Guatemala and to the north by the state of Campeche. The Usumacinta watershed (coordinates 18°61 '- 17°25' N; 91°43'- 91°00'W, Fig. 1) begins in Tabasco in the Tenosique´s frontier with Guatemala, and extends to Centla municipality. In Tabasco, the river flows through five municipalities: Centla, Jonuta, Emiliano Zapata, Tenosique and Balancan.

The region is characterized by landscapes of plains and low hills, also areas of lakes and permanent swamps, to lesser degree valleys, canyons and mountains. The predominant climate is humid and warm humid with monthly average temperature between 22 and 28°C and precipitation from 1,800 to 2,500 mm annually.

2.2 Renewable energy potential

The approach employed to analyze the status and opportunities for renewable energy technologies in the study area is divided into two parts (Fig. 2). The first part contemplates the analysis of the current energy use and the energy trends considering a consumption perspective for the five municipalities. The second part regards the assessment of two renewable energy potentials (biogas and solar), based on the main economic activities (livestock) and energy needs in the region. Graphical representations of these potentials were generated using ArcGis 10.0 software.

Finally, as a result of the evaluations, renewable energy technological options to use these potentials to face vulnerabilities were recommended.

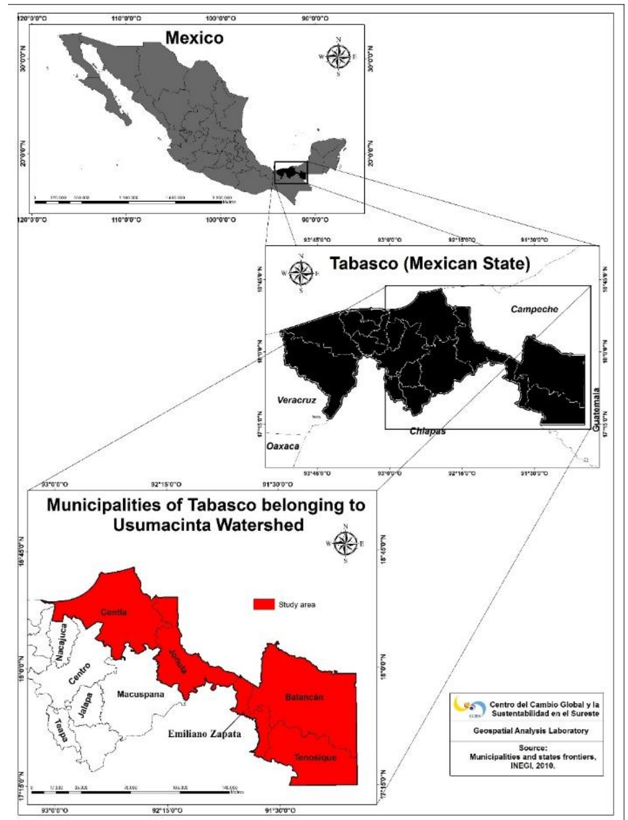

Figure 1 Location of the study area

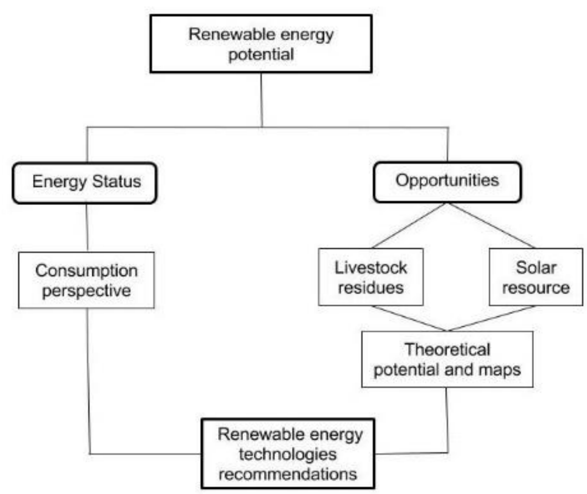

Figure 2 Flow Diagram describing the renewable energy potential studied

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2.3 Biogas potential

Biogas production potential from livestock manure was calculated based on livestock population data with a modified equation from Ríos and Kaltschmitt (2013), shown in equation 2:

$$PB_{g,m,y} = \sum_{m=1}^{n} CG_{g,m,y}\, SP_g PE_g ST_g SV_g FP_g VC \qquad (2)$$

Where PBg,m,y is the theoretical biogas potential in PJ/y, for livestock type g, municipality m and year y; n is the number of municipalities; CG represents the livestock population (heads of animals); SP is the usable manure handling system (%); PE is the manure production (ton/heads of animals); ST is the total solids due to the manure on dry base (%); SV is the volatile solids (%); FP is the biogas production factor (m^3/ton SV) and VC is the biogas calorific value (MJ/m^3). Values from biogas technical conversion factors used, by type of livestock, are shown in Table 1.

Type of livestock	**Total solids [a]**	**Volatile solids [a]**	**Biogas production factor [b]**
	— (%) ——		(m^3/ton of SV)
Cattle (Bovine)	12	80	250
Swine	8	85	375
[a] Steffen et al., 1998; Fiala, 2012 . [b] Batzias et al., 2005; Wellinger et al., 2013.			

Table 1 Biogas technical conversion factors used to estimate the biogas production potential from livestock manure

To estimate the usable manure handling system, a general classification of livestock production system in the region was proposed. A social evaluation through semi-structured interviews and surveys was carried out. Here, the study sample (livestock systems) comes from a non-probabilistic sampling (Snedecor and Cochran, 1981).

The information gathered (considered of exploratory level) was used to estimate the percentage of usable manure handling system according to the zootechnical function and the manure excretion rate due to the livestock weight. In this part, the animal growing stages play an important role in the assessment of biogas production by type of livestock production system. Particularly, a closer approach of manure production is derived as a function of animal weight, leading to a more reliable estimation of biogas production. Biogas production was reported in terms of energy considering that 1 m3 of biogas is equivalent to 21.5 MJ (Batzias et al., 2005) with a methane content from 55 to 60% that generates 1.9 kWh (Tricase and Lombardi, 2009).

2.4 Solar potential

A solar irradiation database was generated to assess the solar potential and graphical representations of the potential were made. To create this database, a grid of 180 points was arranged on the five municipalities of the Usumacinta watershed. The points were geo-referenced in terrestrial coordinates with 10 km neighbor distance. Solar radiation was calculated in every point of the grid. The method used is based on Equation 3 proposed by Reddy (1970) and modified by Estrada-Cajigal and Almanza (2005) for the monthly average daily global radiation:

$$H = 0.0418K \left[\frac{(1+0.8\,n/N)(1-0.2\,r/m)}{0.1\sqrt{h_r}}\right] \qquad (3)$$

Being

$$K = (\lambda N + \psi\cos\phi)10^2 \qquad (4)$$

Where H is the monthly average daily global radiation, ϕ is the latitude, λ= 0.2/(1+0.1ϕ) is a latitude factor, ψi,j is a seasonal factor, n is the mean hours of bright sunshine per day during a month, N is the length of the day during the month, r the number of rainy days during the month, m is the number of days in the month, and h is the mean humidity per day in the month.

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Data collected were processed using the platform ArcGIS 10.0, to obtain maps of average daily solar radiation for every month of the year and the annual average. Note that data had to be obtained numerically since experimental data for solar radiation are hardly available in the state. Also, this method permits to have more punctual estimates of the solar radiation.

Complementarily, communities were visited to know and understand the thermal energy needs and detect areas of opportunities; attention was payed to energy vulnerability. As a result of the above, a set of technological options were proposed. Note that, although the solar resource can be used for both thermal and photovoltaic applications, this work is focused on solar thermal technologies; the photovoltaic perspective will be matter of a further investigation.

3. Results and discussion

3.1 Current status: Usumacinta watershed

Beyond the wealth provided by the ecosystem resources and services in the Usumacinta watershed, the current unsustainable extraction patterns must come to an end. In recent years, the region has faced environmental and socioeconomic changes that have negatively affected the living ecosystems and society. For example, the local populations remain among the poorest in Mexico, being profoundly weakened by the environmental degradation.

Around 3% of the total households in the study area have no electricity and the average electricity consumption per household is 4.7% lower (1768.56 kWh/household) than the rest of the country (INEGI, 2010). Regarding energy resources, traditional biomass such as wood and bagasse are the most employed in the region. In this respect, firewood in rural areas is obtained at several sites, but especially from the places with remnants of original vegetation (as forests or jungles), or regeneration zones with agroforestry systems (as cacao and coffee plantations).

Wood extraction remains a common practice today. It is partly responsible of deforestation; records of this resource extraction date from the nineteenth century (De-Vos, 1988). In the last decade, wood-saving stoves studies has been performed to attend the high marginalization in rural communities (Masera et al., 2007).

Regarding other biomass resources, livestock production figures as the main activity in rural areas, occupying 1.26 million ha, covering 67% of the state (FIRA, 2015). During and after livestock production, a large amount of waste is generated and accumulated. Most of it lacks proper handling, causing environmental, social and economic problems. Most of the local research is focused on livestock systems promotion into organic production systems; other ones suggest technologies, without taking into consideration the biogas potential (Olivares-Pineda et al., 2005).

About the solar resource, it is almost an unexplored subject in the region, although some insights has been done: the Mexican National Water Commission (CONAGUA, 2015) has five weather stations available for the Usumacinta watershed, however, they are insufficient to represent the whole region; a National Inventory of Renewable Energies has been developed by the Mexican Energy Secretariat (SENER, 2015); Hernández-Escobedo et al. (2015) have recently published their investigation on energy resources in the Gulf of Mexico.

Centla and Tenosique, municipalities of the Usumacinta watershed, are the main electricity consumers (graphic 1), with around 60% out of a total consumption of 250,693.24 MWh. Domestic and industrial sectors are the main energy consumers (graphic 2). The latter mainly because of livestock, which is the principal economic activity in rural Tabasco, that demands heat and gas for their processes (CEPAL, 2008).

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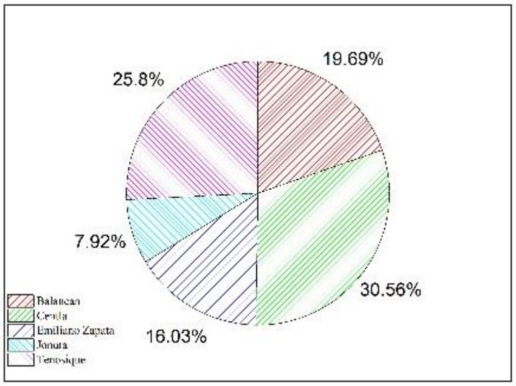
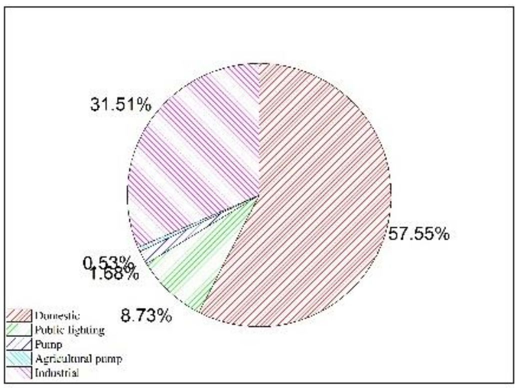


Graphic 1 Electricity consumption by municipality



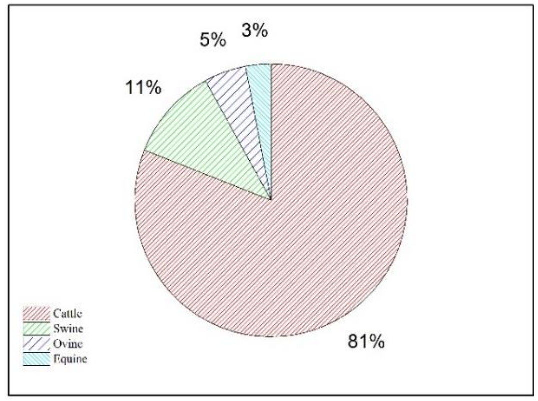
Graphic 2 Electricity consumption by sector

3.2 Livestock production in Usumacinta watershed

In the Usumacinta watershed, there has been envisioned the need to quantify the potential for the production of biogas from livestock manure, especially considering that the state plays a significant role as a national livestock producer; over 1.5 million heads of animals place Tabasco as the 7th in livestock national population of cattle (bovine) (SIAP, 2013).

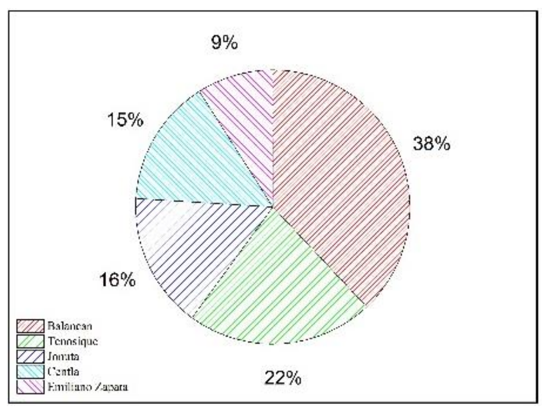
From the total of units dedicated to agricultural and forestry production in Tabasco, 41% develops activities related to livestock sector, where 81% of these livestock system are specifically dedicated to breeding and feeding cattle (Graphic 3.). That is why the importance of swine and cattle production is highlighted in this research.

This activity concentrates around 92% of the total livestock population which daily generates biomass.

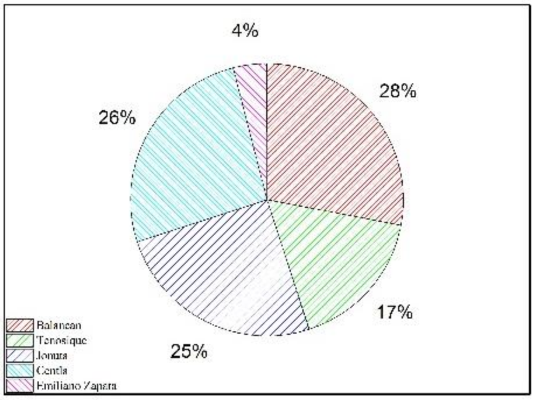


Graphic 3 Livestock population distribution in Tabasco, Mexico. (Based on data from INEGI, 2012).

Related to bovine livestock population, Tenosique and Balancan have 117,512 and 62,784 heads of animals, respectively (Graphic 4), that represent more than 50% in the Usumacinta watershed.



Graphic 4 Livestock population distribution by municipalities of the Usumacinta watershed: bovine swine



Graphic 5 Livestock population distribution by municipalities of the Usumacinta watershed: Based on data from INEGI, 2012

The situation about the swine population is different; the region of the Usumacinta does not concentrate a relevant number of heads of animals. There are 9,024 and 6,515 heads of animals in Centla and Balancan, respectively (Graphic 5). Over 80% of swine population is concentrated in other region of the state: the "Chontalpa" region is one of them, whose municipalities have the largest livestock population.

The livestock production systems in the region in general refer to the type of management or production of animals. In this part, this classification provides a useful tool to estimate the usable organic matter. The characteristics of these production units are decisive for the excretion collection in order to be more regulated and systematized, increasing the technical feasibility for biogas production.

In this sense, the prevailing bovine livestock production system in Tabasco (90%) is free and controlled grazing (Table 2). Free grazing production system is typical in humid tropical regions, where traditional livestock railings or dual purpose (Rivas and Holmann, 2002) allows the joint production of meat and milk based on native cattle crossed with Zebu cattle and European dairy breeds (Manjarrez-Muñoz et al., 2007).

Municipality	Total population [a]	Livestock production system			
		Free grazing	Controlled grazing	Feedlot	Semi-feedlot
		—Heads of cattle—			
Balancan	117,512	77,427	32,101	1,706	5,256
Centla	44,855	25,357	8,791	587	6,249
Emiliano Zapata	29,133	18,352	7,503	994	2,178
Jonuta	50,410	40,249	3,491	386	3,849
Tenosique	62,784	36,760	19,613	1,533	3,909
[a] Considering the production systems reported by INEGI, 2012.					

Table 2 Livestock production systems for cattle (bovine) in Tabasco.

For the case of swine livestock, the production system is performed generally in formal farms or backyard properties. Animals produced in backyard properties, are usually for consumption as opposed to formal farms where their main purpose is marketing. On average, 73% of the swine population is confined into seeking diverse stages of production: stallion, belly, younger than 8 weeks and fattening (Table 3).

Municipality	Usable manure handling system	
	Swine	Cattle
	———(%)———	
Balancan	77,427	32,101
Centla	25,357	8,791
Emiliano Zapata	18,352	7,503
Jonuta	40,249	3,491
Tenosique	36,760	19,613
Average	73.00%	9.82%
[a] Considering INEGI, 2012.		

Table 3 Usable manure handling system for biogas production by municipalities

Regarding the amount of manure excreted per animal, international typical values report 8 kg manure/animal-day for the case of cattle manure and 2 kg manure/animal-day in the case of swine (Arthur et al., 2011). In order to have a better approach in the calculation of manure generated as a function of weight or zootechnical functions, Table 4 shows the data proposed to estimate the approximate manure production.

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Type of livestock	Zootechnical function	Approximate weight	Manure production [a] [b]
		—— (kg) ——	
Cattle	Dairy cattle (adult cow and calves younger than 7 months)	425	34
	Semental (adult bull)	532	42.5
	In development or fattening animals (breeding calves or heifer)	255	20.4
	Beef cattle (Bovine from 12 to 17 month)	297.5	23.8
	Dual purpose (cattle)	318.7	25.5
	Working animals (from 22 to 32 months)	282.5	30.6
Swine	Pig stud	180	5.03
	Sow	150	5.03
	Pigs Below 8 weeks	20	1.8
	In development or fattening	75	5.33

[a] Considering a daily excretion rate of 8% of the living weight.
[b] Considering a daily excretion rate of 2.93% for pig stud, 3.35% for sow, 9% for pigs below 8 weeks and 7.11% for developing or fattening animal (FIRCO-SAGARPA, 2012).

Table 4 Approximate weights and manure production (wet basis) from livestock based on the zootechnical function for type of livestock in the Usumacinta watershed

3.3 Biogas potential from livestock manure.

In Mexico, the national biomass potential from livestock residues was reported as 148 PJ/year (Libro Blanco de la Bioenergía en México, 2006). In Tabasco, the biogas potential calculated from livestock manure (bovine and swine) represents less than 1% of the national potential with 0.40 PJ/year.

The theoretical potential for biogas production from cattle residues is estimated as 124 TJ/year. The potential value for each municipality is presented in Figure 2.

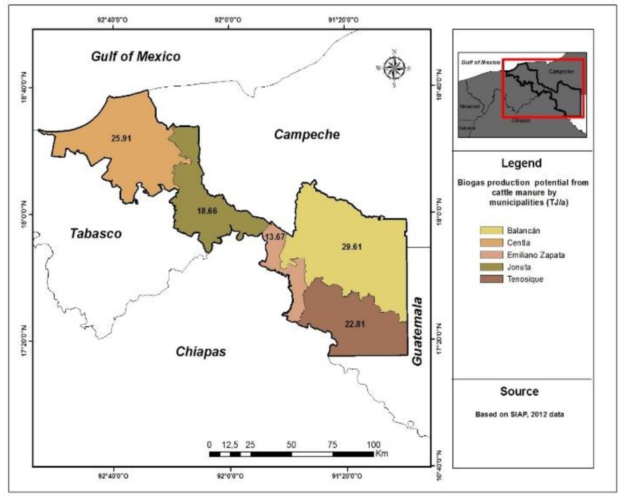
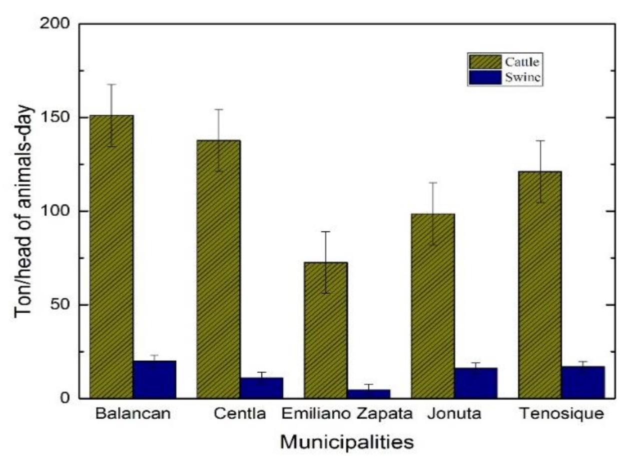


Figure 2 Biogas production potential from cattle manure (feedlot) by municipalities in the Usumacinta watershed (TJ/a)

Centla and Balancan present the greatest biogas potential with 29.6 TJ and 25.9 TJ for 2007.

This value is relatively small considering that the amount of manure livestock comes only from stables (Graphic 6); besides, these municipalities have the largest number of production units in the state, with 3,045 and 2,811, respectively (INEGI, 2012).



Graphic 6 Livestock manure production (feedlot) from cattle and swine by municipalities of the Usumacinta watershed

For the case of livestock residues, estimating the potential not only depends on the number of animals; it was found in this investigation, that despite the municipalities in the region of the Usumacinta concentrate a large number of animals in the state, the potential for biogas production from energy systems such as biogas digesters is affected by the livestock production systems in the region that are based on free grazing regime (near 90%).

A free grazing system yields not only low productivity, but also negative environmental impacts by a lack of sustainable approach, such as excessive loss of forage which leads to degradation of vegetation, increased erosion and loss of soil fertility, among others (FAO, 2014). From the point of view of the biomass resources for energy production, livestock produced in large areas difficult the feasibility to collect of organic material that would be strategic in energy production and valorization of these residues as compost or bio-fertilizers.

In this sense, it is desirable to migrate to other production systems such as intensive silvopastoral systems, as a practice that has been widely recommended for the humid tropical regions (González-Espinoza, 2013). The use of these systems will allow reducing the environmental impact from traditional production systems, increasing the capability of using the manure in a systematic way and promoting a long due sustainable development for the region.

A comparative case about the importance of livestock production systems in the biogas production is the Belgium case. Tabasco has a similar surface than Belgium (25,267 vs. 30,528 km^2), but unlike Tabasco, is the intensive system of livestock production that has allowed Belgium to have a proper use of manure, and a biogas production of 341 GWh (Valbiom 2012,) covering most of its energy needs.

In the case of Tabasco, the biogas potential estimated is one tenth (35.05 GWh) compared with the production of Belgium. However, even using 10% of the livestock manure generated (referring to the manure accumulated in the stables), the energy generated could power 7,851,993 refrigerators under the assumption that 1 m^3 can supply energy to a 14 ft^3 system for 10 hours during a year (Samaoya, 2012), or replace the use of 27,246 tons of firewood, considering that 1 m^3 prevents the use of 3.47 kg of firewood (UNESCO, 1982; Van Buren, 1974).

In relation to swine livestock residues, the biogas production potential is 13.55 TJ coming from 24,715 tons of fresh manure annually. Balancan and Tenosique have the highest potential in the Usumacinta watershed (Fig. 3); however, there are other municipalities in Tabasco, Huimanguillo (9.44 TJ) and Cardenas (7.32 TJ) with higher potentials. The swine production system, unlike bovine, has more feasibility of manure collection, since about 70% of this production is in fattening farms and stables.

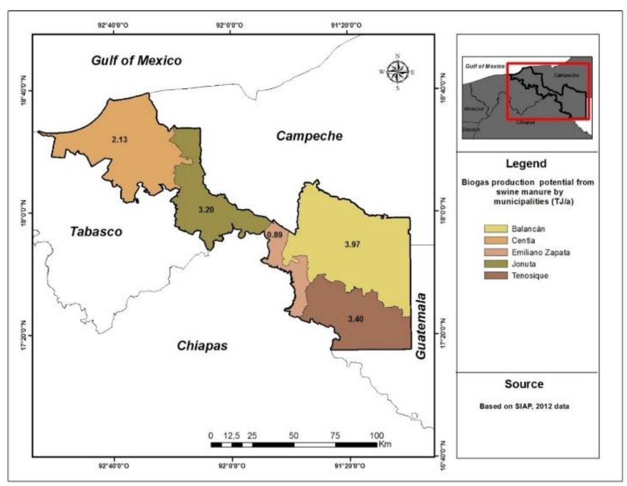


Figure 3 Biogas production potential from swine manure (feedlot) by municipalities in the Usumacinta watershed (TJ/a)

In general, as seen above in this first analysis of biogas potential, although livestock production systems are not the most suitable for the state context, proper utilization of these biofuels can mean savings in heat and power generation (Weber et al., 2012), which can help increase profitability in the agro-system. Given the relevance of the variety of applications of this bioenergy, Fig. 9 shows those sites with potential for biogas production as a priority stage.

This scenario is oriented to those sites with a relevant theoretical potential for the production of biogas that can be used to generate electricity or heat. Specifically, it considers the bovine and swine productions units indexed in the state registry, with a considerable number of animals and feasible production system for manure collection.

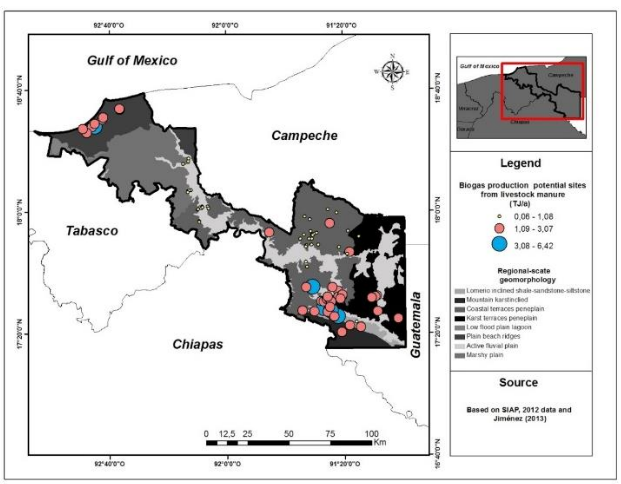


Figure 4 Sites with potential for producing biogas from livestock manure in the Usumacinta watershed in Tabasco

Casas-Prieto et al., (2009) states the requirement of at least 300 heads of animals (cattle) for a biogas production system to be profitable, while the technical specifications for the biodigesters FIRCO-SAGARPA (2012) recommends at least 100 heads of swine for profitability, too.

In this sense, sites with low potential are discarded in these priority approach; however, the possibility to install biogas systems as the "plastic bag digester" type or implementing other technologies for manure management in those production units where the number of animals is lower than recommended by specialists is not ruled out.

As a complementary analysis, the geographical location of these sites, considering the geomorphopedologic regions bounded by Jiménez-Ramírez (2013) are presented. It is noted that for Balancan and Tenosique, most sites belong to coastal and terraces peneplains zones (Figure 11); these are considered knolls in watersheds, characterized by low hills or ridges (Jiménez-Ramírez, 2013). On the other hand, the sites located in Centla are in plain areas of beach ridges considered of regular flooding. It is important to emphasize the importance of linking the extraction, exploitation and production of energy resources with environmental factors such as the geomorphopedological landscapes of Tabasco. To combine these type of criteria for the analysis of the potential of biogas is an essential exercise and it is the prelude to estimate future potentials that involve sustainability indicators.

In general, the potential sites are located in areas with geomorphological landscape conditions characterized for being susceptible to flooding, high water table, salinity and sandy texture in plain (Jiménez-Ramírez, 2013) that must be considered given that they restrict the use of agricultural land and their suitability to make deep excavations for the installation of biogas systems. Thus, installation and setup of the systems for the production of biogas must contemplate these conditions. In this sense, studies on the economic, social and environmental potential of technology are imperative to ensure sustainability. Finally, about manure uses and final disposal is not different from the current management of livestock residues in other states in the country.

Derived from the social assessment, it was found that 78% of producers interviewed dumps the livestock manure directly on the soil around their stalls; 20% use the livestock manure to produce a fertilizer (non-commercial) and 2% use to produce an enriched food to others animals. Most of the producers interviewed shows interest in environmental improvement; however, they are unaware of any applicable technology.

3.4 Technological options for manure management

One of the most common practices related to livestock manure management in the study is the direct disposal on the soil without any use. Studies show that physicochemical composition on soil can be affected by the exacerbated application of livestock manure directly, causing changes in salt content, mainly affecting water bodies, producing leach that reach groundwater and contributing to release greenhouse gases (Pampillón-González et al. 2014), (FAO, 2006).

Considering this situation, some recommendations about manure management technologies are given according to the type of process (Fig. 5). Biological processes are considered a promising technology for the region, for example composting and the use of biodigesters that can be a viable option for the use of waste in energy generation alternative.

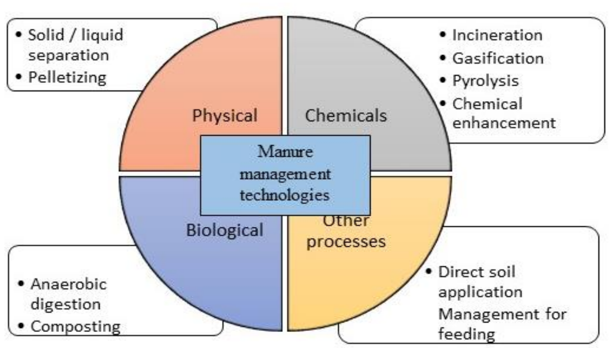


Figure 5 Technologies for the management of livestock manure. Modified from the guide for the selection of technologies for manure management (Porter et al., 2010)

3.5 Solar thermal

The maps obtained for the average daily solar radiation for the highest and lowest solar radiation months, and the yearly solar radiation maps are presented. Figure 6 shows the global average daily solar radiation (kWh/m^2/d) for the month of August. The average radiation is 5.26 ± 0.03 kWh/m^2/d. It is August the month with highest solar radiation during the year, with relatively small variations. This value is above the national annual average of 5 kWh/m^2/d (CONUEE, 2014), surpassed in four months, though the annual average of Tabasco is lower. For the month of August, Centla and Jonuta share the highest average daily solar radiation while Balancan's northeast has the lowest.

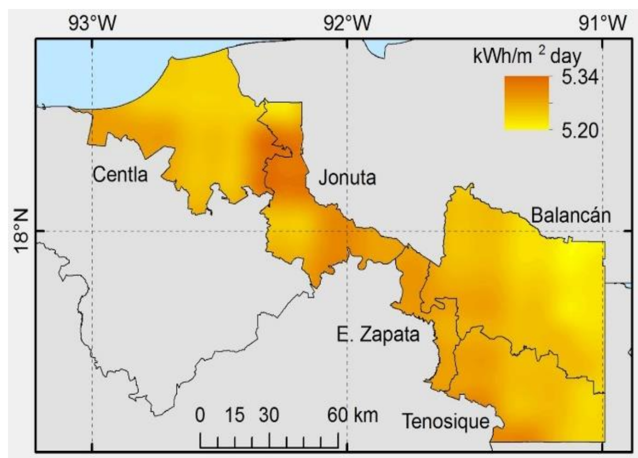


Figure 6 Average daily solar radiation (kWh/m^2/d) for August in the Usumacinta watershed in Tabasco, Mexico

Figure 7 shows the global average daily solar radiation (kWh/m2/d) for December, with an average of 3.66 ± 0.07 kWh/m2/d, which categorizes as the lowest solar radiation month during the year. There are negligible variations in the region, except for the Southwest of Centla with slightly higher average. These levels of radiation can be useful for low temperature applications like water heating for homes, laundry or preheating.

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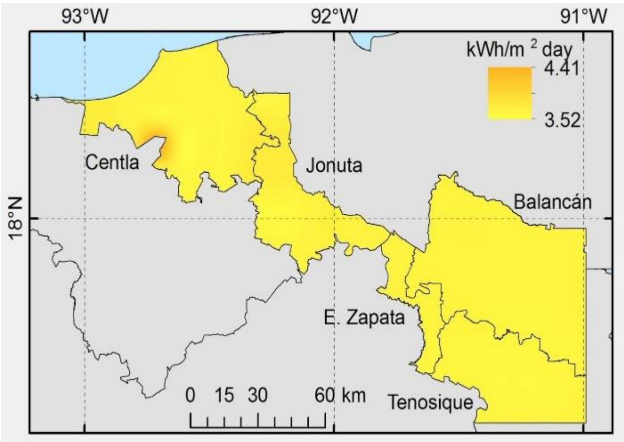


Figure 7 Average daily solar radiation (kWh/m²/d) for the month of December, for the five municipalities of the Usumacinta watershed in Tabasco, Mexico

The yearly average daily solar radiation is shown in Figure 13. The annual average is 4.64±0.53 kWh/m²/d; this value is consistent with data from the Mexican Energy Secretariat (CONUEE, 2014), that estimates it below 4.7 kWh/m²/d. The municipalities of Centla and Jonuta show the highest annual average daily solar radiation, while Tenosique has the lowest. With these levels of irradiation, medium and low temperature technologies can be thought as strategies to deal with thermal energy needs presented in the Usumacinta watershed.

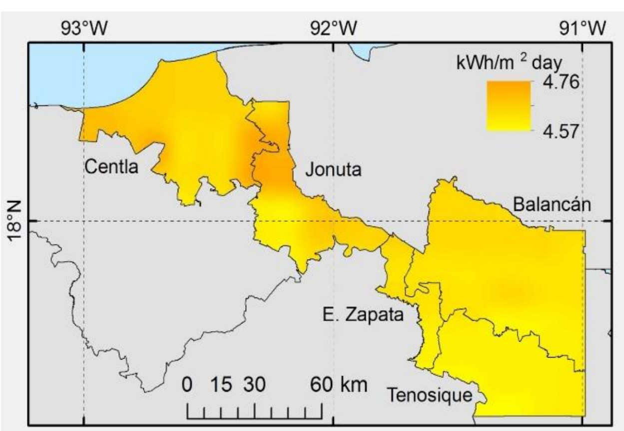
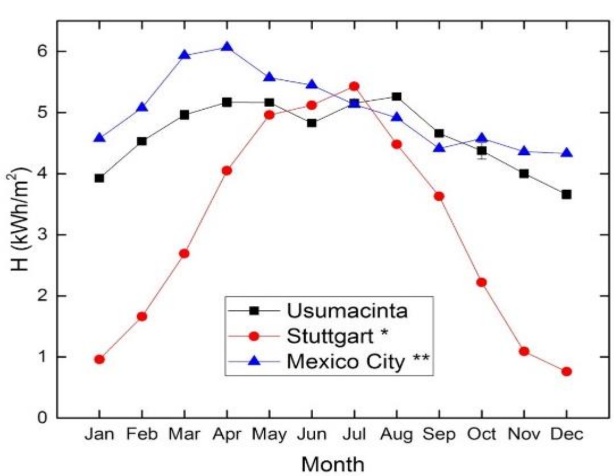


Figure 8 Yearly average of the daily solar radiation (kWh/m²/d). Data for the five municipalities of the Usumacinta watershed in Tabasco, Mexico

To have a broader perspective, it is important to analyze the average daily solar radiation behavior throughout the year; Figure 15 shows the monthly average daily solar radiation for a whole year. Only two months have average daily radiation below 4.0 kWh/m²/d (January and December), and other two below 4.5 kWh/m²/d (October and November). According to the Mexican Standard Normativity (NMX-ES-004-NORMEX-2010) for solar water heating thermal systems, a minimum of 17 MJ (4.7 kWh/m²/d) is required for an acceptable test. This value is reached during eight months in the Usumacinta watershed. Note however, that in other countries like Germany, with average of 3.6 kWh/m²/d (SolarGis, 2015), energy policies have lead them to produce up to 6.9% of their consumption of electric energy with solar energy.

Low and medium temperature needs can be fulfilled with the use of solar technologies all year long, and high temperature applications might be implemented for seasonal use. High temperature is demanded mainly by industrial processes (heat and preheating).



Graphic 7 Monthly average daily solar radiations. Comparison of the solar radiations of the Usumacinta watershed, Mexico City and the German city of Stuttgart.
*Duffie and Beckman (2013); **Hernández-Escobedo et al., (2015).

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It is important to highlight that the use of solar technologies for low, medium and seasonal high temperature processes, yields economic and environmental benefits, such as savings in fuel consumption and reductions of global warming and greenhouse emissions.

3.6 Technological options for the use of the solar resource

In the state of Tabaco, only 6.6% of the population is exempt of vulnerability (CONEVAL, 2014) in the study region. The shortcomings suffered exceed the regional and national averages. Poverty reaches from 65.4% to 80.3% of the population, what makes people to spend most of their incomes in food (ENIGH Survey, 2015). These conditions reduce their access to energy. In general, the thermal needs of the population are usually satisfied with fossil fuels, like LP gas; however, the high prices of these fuels restrict the access. The thermal energy approach presented can provide a complementary access to energy services in these populations.

Below are presented the main thermal needs identified in the region and the technological proposals (Table 5). Mainly, energy needs were identified in what regards to food, health, temporary accommodation, industry and fishing.

Sector	Thermal energy needs	Thermal technologies	Benefits	Barriers	Target population*
Feeding	Cooking of corn to prepare food and drinks	Solar cookers	Reduction in use of firewood	Long cooking times, learning curve, disbelief	Over 70,000 households
Health	Sterilization and laundry	CPC, Dish concentrators	Access to sterilized equipment and cloths	Initial investment, learning curve	254
Temporary accommodation	Hot water for showers, laundry and food	Flat plate collectors	Economic savings	Initial investment	978
Industry	Pasteurization, sterilization of milking equipment	Flat plate, evacuated tube collectors, Dish concentrators	Economic savings, increase in production, cleaner equipment	Disbelief, initial investment	643
Fishing	Refrigeration	Absorption refrigeration systems	Preservation of fish, economic savings	Learning curve, not-automatic, intermittent	56

* In terms of the households and economic activities in the region of the Usumacinta watershed (INEGI, 2015).

Table 5 Opportunity areas for the advantageous use of solar thermal technologies in the Usumacinta watershed in Tabasco, Mexico

Feeding

In Mexico, human consumption of corn reaches 22 million tons (out of a total of 30 millions). The human uses of corn in the region include the preparation of tortillas, tamales and a traditional drink called pozol; there are 123 tortilla producers (INEGI, 2015b); preparation of tamales and pozol is a common practice in the more than 70,000 households, too. Nixtamalization is an important process to prepare tortillas, which involves the corn cooking in a mixture of water and lime to improve food quality and texture (Rangel-Meza et al., 2003); tamales and pozol also need boiling, but no lime. Cooking 1 kg of corn requires around 4 L of water boiled from 90 to 120 min. The energy for this process is gotten from firewood or fossil fuels, however, solar thermal technologies can also provide energy for these purposes. Solar cookers are used to prepare foods that involve some kind of cooking. There are primarily two types: Fresnel-Dish and box solar cookers (del-Río-Portilla et al., 2010).

Health

Private practice is common in the Mexican health system; sterilization is of primary importance for physicians and dentists who usually do not have the appropriate equipment. Proper sterilization requires 121 °C and from 137.9 to 220.6 kPa (20 - 32 psi) for times between 3 and 30 min (Brown and Merritt, 2003).

Previous studies reveal the relevance of solar sterilizers in introducing quality standards in areas with high degrees of marginalization and vulnerability (Young, 2012; Boubour et al., 2014); in the Usumacinta watershed, susceptible to floods or power shortage, this kind of technology increases adaptation, and minimizes risks of infection.

Temporary accommodation

There are 978 economic activities in the Usumacinta watershed devoted to temporary accommodation (INEGI, 2015b). The technology of flat solar collectors for water heating in Mexico has reached maturity, and potential of savings in Hotels has been previously studied (Delgado and Campbell, 2013).

Fishing and industry

There are 275 manufacturing industries in Tenosique and Balancan (INEGI, 2015b), standing those of milk production. Freezing to -25 °C is a need for the 56 economic activities in the region dealing with agriculture, animal breeding and exploitation, forestry, fishing and hunting. Several technologies as flat plate, evacuated tubes or dish solar collector, integrated to the pasteurization process can be efficiently used in dairy industries (Ray and Jain, 2014; Dobrowsky, 2015).

For the case of fisheries, absorption refrigeration systems can be implemented to address this issue (Táboas et al., 2014; Sarbu and Sebarchievici, 2015); however, refrigeration challenges require studies and monitoring to establish sustained and realistic scope in the region. Regarding applications of solar thermal technologies, there is often no single solution. Each challenge has to be evaluated independently to provide a technological solution that is thermally, economically and environmentally viable.

In a population with rooted customs, breaking barriers into gaining acceptance and appropriation of solar technologies (and renewable energies in general) requires diffusion of knowledge and convincing. Integration with other renewable technologies needs to be explored and exploited. Likewise, integration with conventional systems is paramount. Alternate use of technologies at the right times, good energy practices and appropriate energy efficiency assessments can produce higher income and environmental benefits.

3.7 Energy impacts

Table 6 shows the energy impacts of the biogas and solar energy potentials that were estimated for the region, in terms of equivalent number of household benefited and tons of CO_2 equivalent avoided. Over 48,000 households would benefit from using solar thermal technologies if an area of 0.001% was installed with solar technologies with 50% of efficiency; additionally, micro-turbo generators and methane burners would impact in the energy consumption from over 18,000 households. The total emissions avoided would reach 63,042 tons of CO_2e per year.

These results highlight the importance to thrust on the use of renewable energies such as biogas and solar thermal in the Usumacinta watershed. These technologies can reduce the emission of greenhouse gases, mitigate and improve energy security, not to say support adaptation and reduce vulnerability, in such a discriminated region. The information generated is relevant to help in the design of local public policies, overall to improve a sustainable alternative model in the Usumacinta watershed. In this respect, this and further studies are aimed to set the basis of an integral research that involves environmental, economic and social aspects.

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Renewable energy potential	Available energy [a]	Technologies [a]	Benefits	Equivalent Households [b]	Tons of CO_2e Avoided [c]
Solar	66 EJ/y	Type-Dish Stirling Generators. Photovoltaic panels. Flat plate collectors.	Reduction in use of firewood production of heat and electricity	48,151	45,824
Biogas	124 TJ/y	Micro-turbo generators, Methane Burners		18,093	17,219
Total				66,244	63,042

[a] Consider the 0.001% of the energy available in the area studied, 50% of final efficiency for solar equipment's & the use of all the biogas at 100% efficiency.
[b] Considering 1.90372 MWh/household/year (INEGI,2013)
[c] 0.4999 TCO_2e /MWh for the 2013 (http://geimexico.org/factor.html)

Table 6 Energy impacts of the renewable energy potential evaluated

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5. Conclusions

The current research shows the biogas and solar potential from the five municipalities of the Usumacinta watershed in Tabasco, Mexico. Based on the methodology proposed and data generated, a biogas (from livestock residues) and solar potential of 124 TJ/y and 66 EJ/y were estimated, respectively. It is important to note that these potential are theoretical:

To actually account the real potential in each case, they must meet real operating conditions, geomorphologic conditions, state of the art of the technology, economic, feasible and, in general, sustainability criteria. Geo-referenced maps were generated to show the spatial and temporal distribution of the potentials in the study region. The biogas production potential found is considered low and is directly influenced by the livestock production systems.

However, there are biological-based technologies such as composting or biodigester that are viable alternatives to the use of livestock residues technologies in the region. The daily average solar radiation potential of 4.64 kWh/m^2/d is suitable for the use of low and medium temperature applications throughout the year. Important areas were identified for applications in different sectors (feeding, health, temporary accommodation, industry and fishing) that could be met with a set of solar concentrators, flat plate and evacuated tube collectors. Areas of opportunity for using biogas and solar thermal technologies were assessed, paying special attention to the situation of vulnerability (for energy) of the inhabitants of the study region.

The information obtained in this research seeks to provide elements for the analysis and design of energy policies for local planning; also to promote saving measures and technical proposals that will permit to generate opportunities, improve life quality, and preserve the environment.

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