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Biocombustibles y su potencial en el mercado energético mexicano - Biofuels and their potential in the mexican energy market

Samantha A. Paredes-Cervantes[1] Luis Felipe Barahona-Pérez[2]
Francisco G. Barroso-Tanoira[3] Donny V. Ponce-Marbán[4]

Resumen

Debido a que los biocombustibles representan una opción satisfactoria de energía renovable para México, el objetivo de esta investigación fue explorar y describir el estado actual de las políticas de biocombustibles en este país, así como sugerir estrategias para incrementar su potencial en el mercado energético. El método se basó en una revisión de diferentes estudios y entrevistas a importantes productores y académicos expertos. Los resultados indican que el biogás es el biocombustible con el más alto potencial de desarrollo, seguido por el bioetanol, pero las oportunidades para el biodiesel son reducidas, principalmente debido a una insuficiente producción de materia prima. Se requiere una política de incentivos fiscales para mantener a los productores en el mercado.

Palabras Clave: biocombustible, bioenergía, política energética, mercado de combustibles, cultivos para producción de energía.

Clasificación JEL: O13, Q01, Q32, Q42, Q43.

Abstract

As biofuels could represent a satisfactory renewable energy option for México, the objective of this research was to explore and describe the current status of biofuel policies in this country, as well as suggesting strategies for increasing their potential in the energy market. The method was based on a review of different studies and interviews to important producers and expert academics. Results

1- Adscripción: Centro de Investigación Científica de Yucatán AC, México. Correo electrónico: samanthaapc@gmail.com
ORCID: http://orcid.org/0000-0002-3843-3608
2- Adscripción: Centro de Investigación Científica de Yucatán AC, México. Correo electrónico: barahona@cicy.mx
ORCID: http://orcid.org/0000-0003-0204-6566
3- Adscripción: Universidad Anáhuac Mayab, México. Correo electrónico: francisco.barroso@anahuac.mx
ORCID: http://orcid.org/0000-0002-2035-2113
4- Adscripción: Bajío Tecnología Industrial S.A. de C.V., México. Correo electrónico: donnyponce@gmail.com

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indicate that biogas is the biofuel with the highest development potential, followed by bioethanol, but chances for biodiesel are reduced mainly because of insufficient feedstock production capacity. A fiscal incentives policy is required to maintain producers into the market.

Keywords: biofuels, bioenergy, energy policy, fuel market, energy crops.

JEL Classification: O13, Q32, Q42, Q43

1.Introduction

Problem statement

To reduce its dependence on fossil fuels and greenhouse gas (GHG) emissions, Mexico has shown interest in the development and use of renewable energy. In 2015, 87.2% of the total energy demand in Mexico was supplied by fossil fuels, with 43.8% consumed by the transportation sector, according to the Energy Secretariat (SENER, 2016). And although electricity could be supplied by alternative technologies like solar energy (photovoltaic and thermal), geothermal and wind, due to high energy density requirements, the transportation sector still depends on liquid fuels, where biofuels could be an important alternative (Caspeta, Buijs and Nielsen, 2013).

At global level, unfavorable conditions for biofuels commercialization exist in many countries, such as low per capita income, inadequate legislation for their promotion, difficulties in acquiring technology and feedstock, etc. The United States, Brazil, Argentina, Germany and China have established consumption mandates, tax incentives or tax exemptions because the insufficiency of raw materials to cover the demand has generated high costs and an unsustainable inclusion strategy in their energy matrix (Skogstad and Wilder, 2019).

Many countries have fostered the production and use of biofuels at industrial levels, but these fuels represent only 4% of the global consumption in the road transportation market (International Energy Agency, 2017). This underwhelming replacement of fossil fuels by biofuels is due to uncertainties related to their origin and implementation. For example, first generation biofuels compete for the land and water required by food crops, so their sustainability is questioned because of their environmental impacts, which are high in most categories. Besides, production costs are higher than for fossil fuels (Fiorese *et al.*, 2013). Even so, biofuels are convenient because they represent greater energy security and important GHG reductions, in comparison with fossil fuels (Hernández-Pérez *et al.*, 2019).

Almost half of the world production of biofuels in 2018 came from North America, with the United States having the highest share of production (43.5%). Although Mexico contributed with 0.1%, it represented an increase in its production of 276.9% compared to 2012. As for Central and South America, Brazil (22.5%) and Argentina (3.4%) are the countries with the highest contribution. In the case of Europe, France (2.7%) and Germany (3.9%) were the countries with the highest production, and China (2.5%), Indonesia (3%) and Thailand (2%) were the main producers in Asia (BP, 2018).

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The World Energy Council reported that in 2013, biomass supplied 10% (50 Exajoules, EJ) of the annual primary energy consumption in the world and 4.22% was produced in Mexico (SENER, 2014). This energy comes mainly from firewood and natural coal, among other materials that are widely used. According to the U.S. Energy Information Administration, EIA (2019), wood is used in homes throughout the United States for heating (as cord wood in fireplaces and wood-burning appliances) and as pellets in pellet stoves. In 2018, wood energy accounted for 2% of total residential energy consumption. In the electric power sector, there are several power plants that burn mostly wood to generate electricity, and some coal-burning power plants burn wood chips with coal to reduce sulfur dioxide emissions. The potential of biomass for 2050 is estimated at 1,500 EJ per year, although scenarios that take into account sustainability aspects (environmental factors, availability of water and others) indicate a lower potential, between 200 and 500 EJ. The global demand for primary energy by 2050 is expected to be between 600 and 1,000 EJ, so that biomass could contribute between 25-30% of the future energy mix (World Energy Council, 2013).

On the other hand, liquid biofuels have had a higher growth rate for transport and received more attention. Today they represent 1.5% of total transport energy consumption. However, it is projected that by 2030 consumption will grow 10 to 20 times compared to current levels (World Energy Council, 2013). To reduce the environmental impact of fossil fuels use, Mexico have signed agreements with the aim of reducing their use.

Mexico has committed (*e.g.*, the 2015 Paris Climate Agreement) to lower its GHG emissions, which is consistent with existing government policies. Published in February 2008, the Law for the Promotion and Development of Bioenergy (*Ley de Promoción y Desarrollo de los Bioenergéticos*, 2008) emphasizes the development of bioenergy with special attention given to bioethanol, biodiesel and biogas under sustainable conditions and provides support to the Mexican agricultural sector to guarantee feedstock sources.

The Law for Exploitation of Renewable Energies and Energy Transition Financing (from fossil fuels to renewable energy) was first published in November 2008 (Ley para el aprovechamiento de Energías Renovables y la Transición Energética, 2014), and was updated in 2011, 2013 and 2014 to regulate the exploitation of renewable energies with the purpose of taking care of the environment and promoting sustainability. According to this law and several studies conducted by the Ministry of Energy, Mexico's bioethanol development initiatives focus on two raw materials with high levels of production in the country: sugar cane and yellow corn. For yellow corn, the number one agricultural product of the Mexican diet, the Law states that the production of ethanol from this commodity is allowed only if there are surplus inventories from domestic production to meet national demand and an authorization issued by the Secretariat of Agriculture, Rural Development, Cattle, Fishing and Food (SAGARPA, for its name in Spanish). The socioeconomic implications of using corn as feedstock for bioethanol production has been reported by Pérez-Fernández and Venegas-Venegas (2017). However, bioethanol can also be made from imported corn with a permit from the same Secretariat.

In 2005, the Law for the Sustainable Development of Sugar Cane was published (Ley de desarrollo sustentable de la caña de azúcar, 2015). This law created the Center for Scientific and

Technological Sugar Cane Research, which has been conducting studies and projects regarding the development of agroenergy, in particular, the use of ethanol as a fuel and an oxygen additive for gasoline, as well as the best use of cane bagasse for energy co-generation and synthetic gas production. In December 2015, an energy reform was approved in Mexico through the Law of Energy Transition, which included changes in various energy areas. This modification does not alter the ownership of the nation with respect to petroleum and maintains the prohibition on granting concessions over natural resources to private entities. However, it allows the participation of private and social sectors with respect to petroleum exploration and extraction (Ley de Transición Energética, 2015).

Although a general legal framework for research and development of bioenergy exists, it lacks specific legislation for the sale, distribution, and commercialization of the products. This situation creates uncertainty for private investors, which explains why the use of biofuels in Mexico is almost non-existent (BP Global Group, 2013) and why initiatives must come from the government. Additionally, a policy of fiscal incentives (subsidies, taxes, regulatory policies) that support the industrialization of biofuels, similar to policies in the USA, Brazil, and the EU, is necessary to stimulate the use of bioethanol and biodiesel blends (Hernández-Pérez, *et al.*, 2019; Su, Zhang and Su, 2015), especially when fossil fuel prices are low. With current technology, biofuels cannot compete with fossil fuel prices without subsidies or other federal support (Fiorese *et al.*, 2013).

It was reported that high oil prices boosted the demand for bioethanol and affected the corn market in the USA in 2007 (Falcone, 2019). This was a short term boost, but prices tended to stabilize later. In the case of current low oil prices, the production costs of biofuels are too high to be competitive and their consumption is not attractive (Fiorese *et al.*, 2013; Reboredo *et al.*, 2017), situation that can only be mitigated by government policies. This effect is even stronger with second generation biofuels, as investment and production costs are higher than first generation biofuels (Reboredo *et al.*, 2016).

Biofuels are classified in generations, according to their origin and evolution, which can vary according to the author. First generation biofuels are produced from sugar cane, corn grains, beet juice, sunflower seed oil, soybean oil, palm oil, castor oil, cottonseed oil, coconut oil, peanut oil or peanuts, animal fats, fats and oils from cooking and food processing, and organic solid waste. These materials are used to produce bioethanol, methanol and n-butanol (from sugars), biodiesel (from oils and fats) and biogas (organic wastes). Agricultural and forest residues mainly composed of cellulose are the source of the second-generation biofuels. Bioethanol, methanol, syn-gas can be produced from sugar cane bagasse, corn stubble (stem, leaves and cob), wheat straw, sawdust, leaves and dry branches of trees. Some authors consider that biofuels obtained from genetically modified organisms belong to the third-generation biofuels (Research and Markets, 2018).

Regardless of production and consumption challenges, some countries have implemented sustainable strategies for the introduction of biofuels as energy vectors. Despite high production costs, some countries have been able to create a consumption market for biofuels. Some data from the main producers of biodiesel and bioethanol is presented in the following section.

In the USA, biodiesel is the first advanced fuel. Its exponential growth has been driven by the establishment of quality standards in its production (ASTM D6751 and BQ-9000). The largest

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consumer of biodiesel has been the US Army (The Economist, 2014). Since 2005, the USA is the largest producer of corn ethanol (Tsang *et al.*, 2015). Another country, Brazil, is the second largest producer of biodiesel in the world. The current mix used is B5; however, the current government evaluates its modification to B10 by 2020. Petróleo Brasileiro S.A. (Petrobras), patented a technology to convert vegetable oils into green diesel (HBIO process). Soybeans are the source of 77% of the biodiesel produced, followed by animal fats (16%) and finally, the cotton seed, that produces 4%. Brazil is also the second largest producer of bioethanol, with 7.30 million gallons in 2016. The EPA classified sugarcane ethanol as an advanced biofuel, and certifies it as a low GHG emission fuel (-61%) compared to gasoline (Barros, 2016).

In 2017, Argentina reached a record in its biodiesel production with more than 2.7 million tons, an increase of 50% over the previous year. With this production volume, Argentina would occupy the fourth place in the ranking of world biodiesel production, after the United States, Brazil and Indonesia. More than half of its production is destined for export, which placed this country until 2012 as the largest global exporter of biodiesel; the final destination being the European Union. Bioethanol production in Argentina for 2016 was approximately 264,000 gallons, which were obtained mainly from sugar cane, and the production of this biofuel from corn is recent. Argentina is the seventh world producer of ethanol behind India, Canada and Thailand (González Castaño, 2019).

By 2015, China produced 298.5 million gallons of biodiesel, 30% was used as transport fuel, 50% by the industrial sector and 20% for agricultural machinery and fishing boats. The main raw materials for China's biodiesel industry are waste cooking oils and residues from oilseed crushing facilities (Lu, 2019). In China, the mandatory bioethanol blending rate varies between 8% and 12% v/v, depending on availability. It is intended to increase the production of bioethanol from cassava to reduce the use of grains (Scott and Junyang, 2013). In Europe, Germany is the main bioethanol consumer, with approximately 247,000 gallons in 2016. It produced about 70% of its total consumption. Second generation bioethanol reached its highest level, with production increasing 56% since 2015 (Svetlanska *et al.*, 2018).

Objective

Because of the situation described, the objective of this research is to explore and describe the current status of biofuel policies in Mexico, as well as suggesting strategies for increasing the potential of these fuels in the Mexican energy market.

Importance of the study

This study is important because of the opportunities Mexico could have through biofuel production, not only to meet international standards, but also for social development, all of this in an environment friendly way. The macro-environment elements and their possible impacts in the biofuel market have been reported as difficult to control but modifiable, concerning the ways biofuels could be inserted in local markets. These elements are legislation, economic conditions, the technological environment surrounding the product and the socio-environmental conditions

(Arndt, Pauw and Thurlow, 2015; Goetz *et al*, 2018; Gonzalez, 2019; Van Dael *et al*. 2012; Wang 2014).

Although the cost analysis obtained from the production process could be largely determinant to evaluate the possibilities for commercializing a product in the market (i.e., in the case of energy security), it is also relevant to review the public policies because trade instruments (*e.g.*, subsidies or additional costs related to taxes) could change the final price of the product and its alternatives of use (Arndt, Pauw and Thurlow, 2015; Su, Zhang and Su, 2015). Additionally, it is considered that the use of existing agricultural or livestock wastes as feedstock represents an opportunity in Mexico for the production of biofuels.

2. Literature review

2.1. General aspects about biofuels

Demographic, socio-environmental, economic and technological conditions are well established for biofuel production, which could be mainly due to the interest of society (and private companies), which considers biofuels an environmentally friendly alternative to fossil fuels. However, this advantage is strongly overshadowed by the low performance of the other elements in the macro-environment such as the political one, which have been reported in several studies as an impediment to the use of biofuels, according to the Agri-food Sector and Fishing Information System (SIAP, 2018; Arndt, Pauw and Thurlow, 2015; Goetz *et al*, 2018; Talamini and Dewes, 2012; Talamini *et al*., 2013). The political environment for liquid biofuels must be favorable all over the world because the current scenario has several disadvantages regarding quality norms and legal frame for commercialization (Su, Zhang and Su, 2015; Nyström and Bokinge, 2019).

As sustainability is acquiring greater impact as a production criterion, to avoid the problems related to environmental policies, current production processes must be improved to become sustainable methodologies that cause the least environmental impact (Arndt, Pauw and Thurlow, 2015; Scott, Ho and Dey, 2012; Gheewala, 2013). In this aspect, the creation of programs to support agricultural producers and livestock farmers who can devote their efforts to the production of feedstocks for sustainable projects is necessary and has already been done in countries like the US, Brazil, France, and Germany (Goetz *et al*, 2018; Talamini and Dewes, 2012; Talamini *et al*., 2013; Zonin, 2014), where the rate of production has increased positively with the use of these tools.

The situation for liquid biofuels such as bioethanol and biodiesel was analyzed. In general, the situation for bioethanol and biodiesel is the same, with biogas being the biofuel that presented the best conditions for its introduction in the energy market.

In the bioethanol and biodiesel analysis, relevant elements that affect their chances of success in the market showed serious weaknesses, closely related to the macro-environment. The producers showed low development for bioethanol and biodiesel due to a higher consumption of resources and energy at an agricultural phase for feedstock production. Currently, the gasoline and diesel supplier is the government company named PEMEX (Mexican Petroleum).
However, with the new energy law, private companies will be allowed to supply fossil fuels to the market and possibly blends with biofuels. In the case of Mexico, the political and energetic envi-

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ronment of the current government, although it has pronounced itself in favor of the inclusion of renewable energy options, has not carried out modifications in the legislation that present a more favorable panorama for biofuels. The current policies have been focused on the consolidation of the production control and fossil fuel combustion model. According to Forbes, in December 2018, the National Center for Energy Control (CENACE), through an instruction from the Ministry of Energy, canceled the fourth auction of long-term electricity production and, in turn, opted for the construction of a refinery in Dos Bocas, Tabasco, to end the imports of gasoline and diesel from the United States.

The environment surrounding elements, namely producers, inputs, middlemen, potential customers and competitors, were analyzed as relevant elements of the micro-environment of biofuels. All these components can directly modify the quality, service and value chain of the product and must be deeply analyzed to ensure the product has the best characteristics for the market. This is consistent with Gheewala (2013), Scott, Ho and Dey (2012), Wang (2014) and Zonin (2014).

Biogas production by anaerobic digestion is the most developed technology of the three biofuels considered in this study (bioethanol, biodiesel and biogas). Farm manure is the most used feedstock, although landfills also contribute at a lower scale to biogas production. Biogas production processes are more efficient than those for bioethanol and biodiesel. Adequate policies (political environment) are needed to correctly regulate the market for the production and distribution of electric energy through the use of biogas (Arndt, Pauw and Thurlow, 2015; Goetz, *et al*, 2018; Gheewala, 2013; Kalabić *et al*., 2019; Zonin, 2014), which is an environmentally friendly alternative to produce energy (heat and electricity).

As for bioethanol and biodiesel, the support and interest of private companies as potential consumers that consider biofuels as an environmentally friendly alternative to fossil fuels, could also represent an important advantage for biogas. By contrast, biogas production could be a money-saving opportunity for agricultural producers, because its production costs are low and the effluents from the digestion process is good for fertilizer production (Ministerio de Energía y Minería, 2012). The intensive use of fossil energy in the bioethanol production process is another problem that must be solved before it can be considered a clean and sustainable energy source. Biodiesel is mainly produced from waste vegetable oil with alkaline homogenous catalysis—this technology is well established. The use of *Jatropha curcas* oil as feedstock for second generation biodiesel is highly considered as an option because it uses the same technology. However, fruit yields must be improved to attain economic feasibility.

2.2. Biofuels in México

2.2.1. Liquid biofuels

The presence of potential consumers (demographic conditions) could represent a big advantage for bioethanol and biodiesel because of the private companies that view biofuels as an environmentally friendly alternative to fossil fuels. Concerning the economic conditions, the high production cost of bioethanol could make the gasoline selling price more affordable than the E6 (low ethanol) blend. This is the same for biodiesel: the price of fossil diesel, which has a government subsidy, is lower than the price of biodiesel according to the Secretariat of the Environment and Natural Resources (SEMARNAT, 2017), mainly due to high feedstock costs, according to the Secretariat of Social Development (SEDESOL, 2011). The low chance of a successful introduction of liquid biofuels is because of high production costs (Sandar *et al*., 2019; Gheewala, 2013).

The technology for bioethanol production in Mexico will be mainly supported by using sugar cane as feedstock, which means that it is necessary to improve feedstock yields and microbial efficiencies to lower bioethanol production costs. Already established sugar mills will be the first to produce bioethanol from molasses. And although certain countries are more advanced than Mexico in terms of ethanol production and marketing, some authors have recommended that quality standardization at a global level would improve the potential of this product by converting it into a commodity (Sandar *et al*., 2019; Nyström and Bokinge, 2019). In México, although the government has introduced structural energy reforms, none focuses on a strategy for providing a genuine incentive to commercialize biofuel production and use (SENER, 2017).

In the case of biodiesel, one of the first difficulties is oil availability as feedstock. As Eastmond, Sacramento Rivero and Sweitz (2018) mentioned in their case study performed in Yucatan, jatropha oil can be converted to biodiesel through an industrial process that is simple and well known but to attain sustainability. It is necessary to take advantage of the possible by-products that can be obtained during the processing, since the oil in the seed represents only about 10% of the total weight of the tree (Contran *et al*., 2013). Considering biodiesel as the only valuable product, is not economically feasible within the current low-cost petroleum market. As the number of value-added products increase, the economic feasibility of the production chain also increases, and will be even better if the possibility of generating electricity for self-consumption through the use of methane from waste materials from jatropha biomass is included under a biorefinery concept (Eastmond and Sacramento Rivero and Sweitz, 2018; Hernández-Pérez, *et al*., 2019).

There are currently no middlemen considered between the providers and clients for liquid biofuels. This feature is not necessarily considered a weakness because a larger number of intermediaries can generate a strong distribution channel that provides a quality product and also increases the price of the final product (Gheewala, 2013; Su, Zhang and Su, 2015; Talamini and Dewes, 2012).

Considering that the main problem for the introduction of biofuels in Mexico is their high price (compared to fossil fuels), the intermediaries could reduce the chances of success. Although in other countries the value chain through which biofuels are traded mostly includes intermediaries, the lack of subsidies for gasoline and the mandatory use of biofuel policies have generated an important market (Arndt, Pauw and Thurlow, 2015; Goetz *et al*, 2018; Gonzalez, 2019; Talamini and Dewes, 2012; Talamini *et al*., 2013).

The consumption of bioethanol and biodiesel blends at a commercial level is non-existent. The quantities produced nowadays are not comparable to those of fossil fuels. Potential customers that could use biofuel blends are vehicular fleets (36.7 M gasoline engines and 9.2 M diesel engine vehicles). Finally, the real competitors with biofuel blends are fossil fuels (Su et al., 2015) because they are cheaper, so the interest in blends consumption is restrained.

At the end of 2017, because of energy reforms, private enterprises (*e.g.*, Shell, Chevron, Texaco, BP, and Exxon) started selling E10 and B5 blends in México, and this, together with the release of fuel prices (under the control of the government until December 2017), creates a new situation for the fuel market.

2.2.2. Biogas

In the last census carried out biogas production showed good performance in 2011, when there were 721 bio-digesters in Mexico, of which 367 were in operation and 354 under construction (FIRCO, 2011). The most common sources of biogas are agricultural wastes and sanitary landfills (SEMARNAT, 2017). Farms and waste disposal sites take advantage of the residual materials to provide themselves with electric energy, so no providers or distributors are required. Currently, energy from biogas is used for self-consumption, so no clients were detected. Competition in the electricity market is complicated because the main electricity producer is owned by the government, the Federal Commission of Electricity. However, electric energy trading agreements have been gradually opened in Mexico and increased market activity is expected.

2.2.3. Costs and final price of fuels

Bioethanol and biodiesel have higher production costs than biogas. Fiscal incentives, in the form of subsidies, tax credits, or renewable energy programs, have been used in many countries to stimulate the use of blends for transportation (Kanellakis, Martinopoulos and Zachariadis, 2013); Ghoddusi, 2017). While Mexico this is not an exception, it is difficult to assert the production costs of bioethanol and biodiesel because a well-established market for biofuels does not exist. In Mexico, four taxes (three Production and Services Special Taxes (PSST) and a Value-Added Tax (VAT)) combine to account for approximately 30% of the final fuel price.

The federal PSST (f-PSST) is a uniform, nationwide tax. State PSST (s-PSST) is variable from state to state. PSST-CO2, is a carbon dioxide tax implemented to discourage the use of fossil fuels because of greenhouse gas emissions. VAT is a 16% tax (maximum). With the exception of PSST-CO2, biofuels are subjected to the same taxes as fossil fuels. Many of the Mexican states have not legislated on s-PSST for biofuels. However, tax exemptions have been a subject of debate at many levels of government. Table 1 shows the final price and cost breakdown associated with taxes for fossil and renewable fuels. However, in the present conditions of biofuels in México, where pilot plants exist, legislation is incipient and commercial production is non-existent.

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Table 1. *Final price and cost breakdown associated with taxes for fossil and renewable fuels in México, April, 2019*

Cost USD·L-1*					
	f-PSSTa	**s-PSST**	**PSST-CO2**	**VAT**	**Final price**
Premium gasoline	0.15	0.03	0.01	0.16	1.09b
Diesel	0.13	0.02	0.01	0.16	1.04b
Bioethanol	0.19	na	Na	0.04	1.14c
Biodiesel	0.19	na	Na	0.04	1.21c

[a]With government subsidy for fossil fuels. [b]Current prices to consumer
[c]Calculated prices to consumer based on production costs. na = not applicable
* Dollars per liter

3. Metodology

A qualitative study was developed for preparing a strength, weakness, opportunity and threat (SWOT) analysis for verifying the potential of biofuels in the Mexican energy market. For such analysis, different concepts covered in the literature review were taken, as well as the results of an interview to private producers.

3.1. Type, design and method

Interviews in companies and to academics were conducted during the first semester of 2016. The type was exploratory and descriptive, with transverse non experimental design because the interviewed participated just once and there was no manipulation of variables. The method was inductive with fieldwork and the technique was the interview with the corresponding question guide as instrument (Hernández, Fernández and Baptista, 2014).

3.2. Participants, instrument and procedure

Finding established private producers was difficult because of Mexico's incipient biofuel market. However, seven interviews were conducted for ethanol, nine for biodiesel, and seven for biogas, so there were 23 in total. From the total, eleven interviews (48%) were performed in companies dedicated to one of the biofuels and twelve (52%) were answered by academics working in the field of biofuels. In general, the average age of the participants was 38 years old, 22 of them are men and 21 are Mexican. There were 21 with postgraduate education and seven were dedicated to research and development of biofuels or products related to fuels. All were active and just 2 were working.

Some of the companies ventured into this sector for the first time, being the sale or production of biofuels their main source of income. However, most of them were Mexican producers

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or sellers of biofuels as a sub-product or alternative product to their main one, with more than 10 years of profitable operation. From them, seven (30%) had their main activity in the South East of México, and the 70% remaining are from the Center or North. Regarding size, seven were mid-sized and 16 large.

The interview guide followed a structured pattern, which consists of four sections. The first one (eight items) was dedicated to general information about the company: name, address, area of influence, how long it has been in the market, main products, etc. The second section (thirteen items) was dedicated to biofuel production: production levels and costs, selling price, historical sales levels, distribution, clients, self-consumption, etc. The third section (eleven items) asked for information about middlemen, technology production and regulations. Finally, in the fourth section (five items), information about the environment was required: competitors, incentives, taxes, etc. Validity was verified through the judgement of three experts in methodology and the topics covered (Hernández, Fernández and Baptista, 2014).

Care was taken to keep the duration of each interview between 30 and 40 min. The answers were recorded and the data was processed in Excel spreadsheets, where their frequency of mentions was registered and grouped in defined categories. The answers in each category were organized from most to less frequently mentioned, and those categories were ranked the same way. The analysis revealed the opportunity areas and existing strengths for each type of biofuel.

4. Results

4.1. Interview results

4.1.1. Results of interviews in companies

All interviewed agreed that:

Category: problems because of high costs

- The biofuel production is generally unattractive to private enterprises. The prices, in order to be competitive, put the companies in difficulties to generate profits since they have to propose attractive conditions for the clients, even though their production costs are high.
- Producers indicate that high cost is the main problem. The sources for obtaining inputs are limited and the volumes would not allow the satisfaction of demand in a representative market share to continue with the current market scheme.
- None of the companies in current operation sell at retail. They indicate this would not be profitable.
- Companies with more years in the market are those which continue producing bioenergetics because they were able to survive even with low profits. They were already strengthened before their beginnings in bioenergy.

- Production volumes are not exported in any case. No company considers this to be a viable option to date.
- The bioenergy market presents few opportunities for growth for private companies under the current scheme.
- Competitors are scarce because it is a currently unattractive sector.
- The regulatory framework related to the management and generation of biofuels and their quality should be re-evaluated for including bioenergy as a popular product in the market.

Category: *insufficient support for producing biofuels*

- The technology used to produce biofuels is widely known and, as reported, does not represent the main problem of production. They state that the potential inputs are diverse and that this exists throughout the country. However, the sources of production are limited, given that there is not abundance of enough input for industrial production.
- Even though the establishment of production plants would not represent great difficulties in their management and given that permits and regulations related to production plants are accessible, government support for production is insufficient and difficult to access.

Category: incentives for production

- An incentive to production would be the most appropriate option to promote the supply of these.
- Interest in the commercial production of biofuels is relatively recent. The company with the longest biofuel production is eleven years old. All others have been nine years or less in the bioenergy business.
- Those that produce biofuels have 100% of their production previously agreed, and do not generate surplus.

Category: *problems related to production*

- Up to 80% of companies are not in production period because the commercialization of biofuels has generated higher costs than profits. On the other hand, most of the companies that continue producing bioenergy are those that have other products as their main source of income.
- 80% mentioned that the storage and distribution of ethanol and biodiesel also have many areas of opportunity to generate a marketing scheme, since there is no regulation for these activities.
- 60% of the companies interviewed are not currently producing biofuels. Of this last percentage, only 8% expect to continue their production in the medium term if the conditions of production costs and supply of inputs do not improve.
- Only 20% expect to have a short term growth in its production potential, given the uncer tainty by recent changes in energy in the country and the outlook for the current economic situation.
- Production volumes are not exported in any case. No company considers this to be a viable option to date.

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- To make the process more profitable, it is essential to use by-products that have an aditional income to the company to compensate for the high costs of the agricultural and production stages.

Category: *sustainability*

- The permits and regulations related to production plants are minimal, so regulations must be revised to enhance sustainability.

4.1.2. Results in interviews to academics

Category: *problems because of high costs*

- For ethanol and biodiesel, production levels are very small compared to demand. It would not be possible to cover 10% of the demand with the production currently reported.
- 70% mentioned that in the pursuit of environmental responsibility, high costs must be ac cepted as part of the biofuel conditions.

Category: *value chain*

- 90% mentioned that biofuels do not have intermediaries, which indicates that the value chain must be completely carried out by the ethanol, biodiesel or biogas producer.

Category: uncertainty to producers

- 80% mentioned that the agricultural phase of ethanol and biodiesel production processes, which generate the greatest uncertainty to the producers, is the one that implies a greater consumption of resources and energy, and the one that allocates the majority of costs and investments.

Category: ethanol

- 90% agreed that sugarcane represent an excellent option for the production of ethanol, while 10% consider there is a lack of efficiency in the processes. Alternative products such as agave and nopal must be considered, among others.

Category: biodiesel

- 100% agree that the producers must be independent from PEMEX, but the outlets must be regulated by PEMEX and its subsidiary branches.
- 60% mentioned that there is still no ideal product to be used as a source of oil, which combines an ideal product yield and, at the same time, does not compete as a food source.

Category: biogas

All interviewed mentioned that:

- Biogas is the biofuel with greater possibilities on the market
- The reduction in the operation of the carbon credit program led to a decrease in the interest of the companies that already generated it in a continuous production
- The CFE norms for the cogeneration of electric power do not encourage large producers.

- The generation of biogas can be highly profitable.
- Having companies specialized in designing high quality projects for the generation of biodiesel is very important.
- Biogas producers that currently generate electricity prefer to allocate 100% of their production to self-consumption.

4.2. SWOT analysis

Regarding the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, the elements that strengthen the position of biofuels and opportunity areas were considered for improvement according to different authors (Catron *et al.*, 2013; Okello *et al.*, 2014; Soimu, 2014; Paschalidou Tsatiris and Kitikidou, 2016; Phadermrod, Crowder and Willis, 2019; Georgakopoulou, 2019; Kalabić *et al.*, 2019; Zalengera, 2014) and the interview results. This analysis was performed out considering strengths and weaknesses as current states, and opportunities and threats as future states criteria.

4.2.1. Strengths

The results of the SWOT analysis for the commercialization of bioethanol and biodiesel in Mexico were almost the same. This can be explained by the liquid nature of these biofuels (technology) and will be used in blends with fossil fuel in the transportation sector (normativity). Regarding Strengths, it was found that biofuels are considered a renewable resource, and this is an important aspect of energy security. They are also considered carbon neutral, as their use does not contribute, at the same level as fossil fuels, to an increase of CO2 concentration in the atmosphere.

They are also less flammable than fossil fuels, which is an advantage from an industrial safety point of view. Finally, production processes exist at commercial levels for the three biofuels studied in this work. In the case of biogas, the strengths are that efficient processes are already in the market and can be used to produce energy from waste biomass and transform biomass waste into biogas, which requires low energy inputs compared to the other biofuels.

4.2.2. Weaknesses

For weaknesses, it was found that the main issue is production price. To have similar prices to fossil fuels, optimization of the required industrial processes is necessary. Additionally, incentives to producers could be implemented. Another weakness closely related to this issue is the lower prices of fossil fuels, compared to biofuels.

Although this situation could change in the future depending on international oil policies, feedstock availability is also an issue to be addressed. In Mexico, bioethanol is made from molasses, a sub-product of the sugar industry, and biodiesel is made from vegetable oil waste. However, they are both insufficient to cover the needs of industrial production levels.

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Energy crops are considered as feedstock to produce bioethanol (sugar cane) and biodiesel (*Jatropha curcas*), but environmental impacts generated at the cultivation stage need to be reduced. It has been reported that high emissions to air, water and soil can occur due to the use of fertilizers (Amores *et al*., 2013; Portugal-Pereira *et al*., 2016). In the case of biogas, energy generation will be limited by the composition of the feedstock, which can vary according to its source of origin. There is still the need to increase the efficiency of waste collection systems and the lack of incentives for energy producers to incorporate the surplus of energy into the national grid.

4.2.3. Opportunities

With respect to opportunities, increasing production levels can create jobs in the areas of biofuel manufacturing (i.e., agricultural and industrial). Additionally, the biofuel manufacturing industry would encourage agricultural activity in Mexico. The proposal of programs, agreements and legal reforms related to the production of the three biofuels by the government would endorse newer economic opportunities. In the last three years, there have been initiatives to include ethanol as one of the products in Pemex's portfolio as a 5.8% blend with gasoline (E6). In the case of mixtures, the proportion between both fuels is usually indicated by the percentage of biofuel, preceded by a capital letter (in this way, 5.8% anhydrous ethanol is known as E6, E10 is made up of 10% ethanol and 90% gasoline, and B5 is obtained by mixing 5% Biodiesel and 95% gasoline), offering the largest potential in Mexico's biofuel market. An improvement in cultivation technologies can be seen as an opportunity to reduce the feedstock availability issue.

According to SEMARNAT (2017), the two main crops Mexico has to produce ethanol are sugar cane and grain sorghum. There are 7.2 million ha of sugar cane. This area has a potential yield of almost 270 tons of cane per hectare when the most advanced technologies and varieties are used in optimal environmental conditions, and a yield of 85 L of ethanol per ton biomass or 22,950 L/ha using the best planting and harvesting technologies (Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar, CONADESUCA, 2012). For sorghum, there are 15.8 million hectares with a potential yield of 7 t of sorghum per hectare, producing up to 420 L of ethanol per ton of biomass or 2,800 L/ha with good agricultural practices (SEMARNAT, 2017). For biodiesel, the most competitive crops for its production are palm and soy oil, but *Jatropha curcas* could also be considered. However, crop productivity is still too low for commercial exploitation.

On the technological area, the replacement of fossil fuels by renewable energies as energy inputs on biofuels production processes will improve their economic viability and sustainability. This can be considered an opportunity towards the use of biofuels in the Mexican energy market. With the energy reform, international corporations are able to sell fuels in Mexico. As these companies already sell fuel blends in other countries, there is a possibility for them to do the same in the country. As for biogas, a self-sufficient energy supply could boost agricultural output in the country and there is a high growth potential of installed total capacity of bio-digesters in the country.

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4.2.4. Threats

Regarding threats, natural disasters can jeopardize the availability of raw material (feedstock) and the energy crops grown in zones that can be flooded, destroyed by hurricanes, etc. Climate change will possibly play an important role on feedstocks low productivities. It has been reported that drought and extreme temperatures affect more areas each year. It will be necessary to develop new varieties resistant to these adverse climate conditions. Another threat to the introduction of biofuels in Mexico is the growing concern of real sustainability of energy crops plantations. Oil palm plantations have been the focus of a debate on biodiversity threatening in Southeast Asia (Reuters, 2018). It is possible that in the mid-term, a certificate of plantation sustainability becomes necessary for biofuels feedstock commerce. Finally, the development of new technologies for energy production and the improvement of other renewable energies can reduce the demand for biofuels.

From the three biofuels studied in this work, biogas appears to have the least threats for commercialization. This can be due to the fact that manure, waste water and organic residues are employed as feedstock, whereas the cultivation stage for bioethanol and biodiesel is highly energy consuming and environmental issues are important.

5. Discussion

Biofuel production

In this work, the conditions for a successful transition to a scheme where the energy generation in Mexico could include the commercialization of bioethanol, biodiesel, and biogas were analyzed. First, the inclusion of biofuels in the Mexican energy market will be driven by the need to lower GHG emissions and comply with international commitments acquired in the past, not by the economy of their consumption. To attain this goal, the government must create a well defined legal framework to enhance the biofuel market (Arndt, Pauw and Thurlow, 2015; Goetz *et al*, 2018; Gonzalez, 2019; Talamini and Dewes, 2012; Talamini *et al.*, 2013; Gheewala, 2013; Su, Zhang and Su, 2015).

For these biofuels, the regulations represent an opportunity area as it is non-existent, since it can present an initial panorama according to the conditions that are a priority in the market and thinking of laying solid foundations for energy security. Additionally, the government and private companies in Mexico are currently committed to caring for the environment and their use does not generate an increase in the concentration of CO2 in the atmosphere. They are also less flammable than fossil fuels, which is an advantage from the point of view of industrial safety. Sustainability is acquiring a greater impact as a criterion of production, to avoid environmental problems, that is why policies must be adapted, and production processes improved, to become sustainable methodologies that cause the least environmental impact (Gheewala, *et al*, 2013; Scott, Ho, and Dey, 2012.).

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In this regard, the creation of programs to support agricultural and livestock producers who can dedicate their efforts to the production of raw materials for sustainable projects is necessary and has already been done in countries such as the United States, Brazil, France and Germany, where the production rate has increased positively with the use of these tools (González Castaño, 2019; Svetlanska, *et al*., 2018; Zonin, 2014).

The energy policies that should be considered are similar for both liquid biofuels (ethanol and biodiesel) because they will be used in blends for the transportation sector, and may differ from biogas because this is mainly used in self-consumption and regulated by the electricity sector. To improve the possibility of including biofuels in the energy market, the government policies should focus on creating a road map for each biofuel with clear steps and established dates. However, countries like the US, which have clear policies and legal and economic development plans, are currently facing difficulties in complying with their biofuel consumption targets, mainly due to the lack of production. Therefore, even with an adequate public policy, establishing the use of biofuels in Mexico will be difficult.

The current status of the agroindustry in Mexico indicates that, in the short and mid-term, the main feedstock for bioethanol, biodiesel, and biogas production can be sugar cane, palm oil, and animal manure, respectively. In the long term, sweet sorghum, jatropha oil, and agroindustrial organic waste can complement the feedstock market. Due to high production, transportation and logistics costs, it is necessary to have a diagnosis of the points of potential production and how the points of higher demand are going to be covered. This diagnosis will allow precise projection of the investments required for the infrastructure and management of the blends.

For bioethanol, biodiesel and biogas, Mexico must maintain and improve its own technology in order to satisfy its energy demand. Fossil fuels will still be used worldwide for a long time and GHG emissions will be mitigated by the use of sustainable biofuels.

Currently, private companies can sell liquid fuels in Mexico, and there are no limiting clauses in this regard (Forbes, 2018). These companies may sell E10 and B5 mixtures, and this, together with the release of fuel prices (under the control of the government until December 2017) could create a new situation for the market of fuels in Mexico. In the case of biogas, cogeneration seems to be an economically viable option, but the Federal Electricity Commission must review its commercial policy to guarantee that large-scale producers can sell surplus energy.

The energy policies and resource management are more focused to the resolution of immediate problems, such as the supply of energy, economic difficulties and social and political issues, instead of the procurement of sustainable long-term use of biofuels.

The need of fiscal incentives

The final prices of fossil fuels are lower than those of biofuels due to the government subsidy on f-PSST. Without subsidization, the final price for Premium gasoline and Diesel would be 1.30, and 1.31 USD·L-1, (being 12.3% and 7.6 % more expensive than bioethanol and biodiesel, respectively. With production and marketing costs of bioethanol (Fuel-Flex, 2018) and biodiesel (SENER, 2017) of 0.91 and 0.98 USD·L-1 respectively, two scenarios can encourage the use of biofuels.

The first scenario would be establishing parity between fossil fuels and biofuels through the expansion of f-PSST subsidies to include biofuels. In this scenario, the final price of bioethanol (1.08 USD·L-1), will be comparable to Premium gasoline, and the final price of biodiesel (1.11 USD·L-1), will be slightly higher than current fossil fuel diesel prices. The second scenario would exempt biofuels from the f-PSST. Without f-PSST, bioethanol and biodiesel prices would be 0.95 and 1.02, respectively, lower than those of fossil fuels. In February 2017, a proposal for such an exemption for bioethanol was submitted to SAGARPA (Zafranet, 2017). Through this analysis, a possible option would be to maintain the f-PSST, s-PSST, PSST-CO2 for fossil fuels to discourage their excessive use. However, as the transportation sector plays a major role on the Mexican economy, the current subsidy to the f-PSST should also be maintained. Finally, renewable fuels prices should not be subjected to f-PSST and the VAT must be kept as part of the final price of both fossil and renewable fuels, as it is an income for the federal government.

6. Conclusions

There is a great potential for biofuel production in México. The strategies suggested, in the case of bioethanol and biodiesel, indicate that the government must adopt a policy of incentives to allow and motivate producers to continue in the market. Regulation of the final price is also crucial, at least while the market stabilizes. It has been reported that if consumers have a choice, they will always pay the lower price (Kleit, Shcherbakova and Chen, 2012; Chen and Kleit, 2016), situation which is more likely to occur in a country with low incomes such as this. In the case of biogas, co-generation seems to be an economically viable option, but the CFE must revise its trading policy to ensure private large-scale electricity producers can sell surplus energy.

The inclusion of biorefinery construction projects, could present a viable option once the production, commercialization and consumption policies are clearly defined. This would allow to control the production processes, to control the prices by means of the exploitation of economies of scale and also to take advantage of the biomass sub products.

Mexico's government will support the use of biofuels. More research and development is required to improve the efficiency and sustainability of the production processes and should focus on using renewable energy inputs, crop improvements and energy policies that guarantee social welfare. Mexico also must maintain (and improve) its own technology to be capable of fulfilling its energy demand (fossil or renewable).

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