www.cya.unam.mx/index.php/cya

Contaduría y Administración 63 (2), 2018, 1-25

International efficiency of biodiesel: An analysis for the case of Costa Rica, Spain, the United States and Mexico

Eficiencia internacional del biodiesel: un análisis para el caso de Costa Rica, España, Estados Unidos y México

Yéssica Yasmín Santos Equihua*, Irma Cristina Espitia Moreno and Rodrigo Gómez Monge

Universidad Michoacana de San Nicolás de Hidalgo, Mexico

Received 9 february 2015; accepted 18 march 2016
Available online 19 march 2018

Abstract

At the international level, there are factors that have led to searches for alternative energy sources, biofuels are among these alternatives. In this context, this research objective is to determine the level of relative technical efficiency of companies producing vegetable oil and animal fat based biodiesel fuels (BAVyGA) in Mexico, in relation to Costa Rica, Spain and the United States and incorporating inputs, also making also use of the model DEA model as a tool for quantitative economic analysis quantitative. The evaluation was applied to the operations of 30 companies during the year 2014 and can guide decision-making in operational areas of Mexican companies to achieve higher efficiency levels. The main finds, which comply with each of the objectives are the following: There is a wide variability in the size and operability of the companies; in addition the American companies are in general those regarded as a benchmarks, due to their higher level of efficiency; and finally, some companies, mainly Mexican and Costa Rican, maintained surpluses in production capacity and the number of employees, that can be used in a best way considering the operations of the North American and Spanish companies.

*Corresponding author.
E-mail address: ysantos@umich.mx (Y.Y. Santos Equihua)
Peer review under the responsibility of Universidad Nacional Autónoma de México.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

JEL Classification: M11, M16, M21, Q01, Q42
Keywords: Biodiesel, Efficiency, Energy Sector, Sustainability.

Resumen

A nivel internacional existen factores que han llevado a la búsqueda de energías alternativas, dentro de las cuales se encuentran los biocombustibles. En este contexto, la presente investigación tiene como objetivo principal determinar el nivel de eficiencia técnica relativa de empresas productoras de *biodiesel a base de aceites vegetales y grasas animales* (BAVyGA) de México, en relación a los presentados en Costa Rica, España y Estados Unidos (EE UU) incorporando variables de entrada y salida, haciendo además uso del modelo *Data Envelopment Analysis* (DEA) como herramienta de análisis económico cuantitativo. La evaluación se realizó a 30 empresas durante el año 2014 y el resultado, permite establecer decisiones en las áreas operativas para que las empresas mexicanas logren un mayor nivel de eficiencia. En los principales hallazgos se observa que existe una amplia variabilidad en cuanto al tamaño y operatividad de las empresas; y además que no se encuentran trabajando en escala óptima; por otra parte las empresas norteamericanas son en general consideradas con mayor nivel de eficiencia. Además, algunas empresas, fundamentalmente mexicanas y costarricenses mantienen excedentes en la capacidad de producción y en número de empleados, que pueden aprovecharse mejor dentro del proceso de producción si se compara con la forma de operación de empresas norteamericanas y españolas.

Códigos JEL: M11, M16, M21, Q01, Q42
Palabras clave: Biodiesel, Eficiencia, Sector Energético, Sustentabilidad.

Introduction

"The constant and marked fluctuations in the price of fossil fuels, the growing concern for the environment, and the responsibilities acquired by the governments at an international scale have led to the search for alternative fuel sources" (Montiel, 2010, pp. 57-58). "The transport sector is the largest energy consumer and with the highest growth rate worldwide. In the next 25 years, the use of gasoline and diesel will double" (Soimmakallio & Koponen, p.3404). In light of this, the use of biomass for energetic uses has drawn more interest. Presently, there are two types of liquid biofuels that could replace gasoline and diesel: bioethanol and biodiesel (Demirbas, 2011, p.18). For the production of biodiesel, the Latin American region has some advantages such as "soil, weather, labor costs" (Janssen & Damián, 2011, p. 5817). However, the procurement methods of these should be observed.

"At a microeconomic level, a great interest has developed with regard to the analysis of efficiency for a group of decision units that have the same technology, the most used procedures with this aim are those based on the production boundaries" (Pastor, 1995). In the present analysis, the DEA model is used to achieve the objective of the investigation, which is to determine the level of relative technical efficiency of the manufacturing companies of BAVyGA of Mexico, in relation to the ones of Costa Rica, Spain and the United States in 30 companies manufacturing of biodiesel derived from animal fats and vegetables oils for the year 2014. "The DEA analysis, as an economic quantitative analysis tool, is valid and broadly used to evaluate

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

the performance of sectors and productive sub-sectors, such as the biodiesel subsector" (López, J., Henao, S. & Morales, M., 2007, p.). This analysis allows the study of each incorporated variable in order to establish proposals for the conditions in which the companies in Mexico should operate so that it can reach a high level of national and international efficiency.

This investigation comprises seven sections. In the first one, we present the context in which the biodiesel sector operates. In the second, we present the fundamental aspects of the investigation. In the third, we develop the theoretical framework where we go back to the theories of sustainable growth and the focus on efficiency. In the fourth we present the design. Subsequently we establish the results of the DEA analysis. In the penultimate we present our conclusions, and finally, the study proposal.

Contextualization of the subject of study

Current situation of the transport sector and alternative energy. According to the *Secretaria de Energía* (Secretariat of Energy) ([SENER], 2013), in its report *"Prospectivas del sector eléctrico 2013- 2027 en* México" (Prospective of the power sector 2013-2017 in Mexico), it is mentioned that the power sector is one of the essential sectors in any economy (p. 9). The CAP ([*Consejería de Agricultura, Pesca y Desarrollo Rural*], 2008) (Council of Agriculture, Fisheries and Rural Development), mentions that "power acquires a great *economical* relevance, as its availability conditions its economy; *social* due to the fact that its access conditions its level and quality of life, and; *environmental* any use of power presents an impact in human population, as well as in the vegetable and animal kingdom" (p. 17).

In the case of Mexico, the detailed information on the importance of power is presented below:

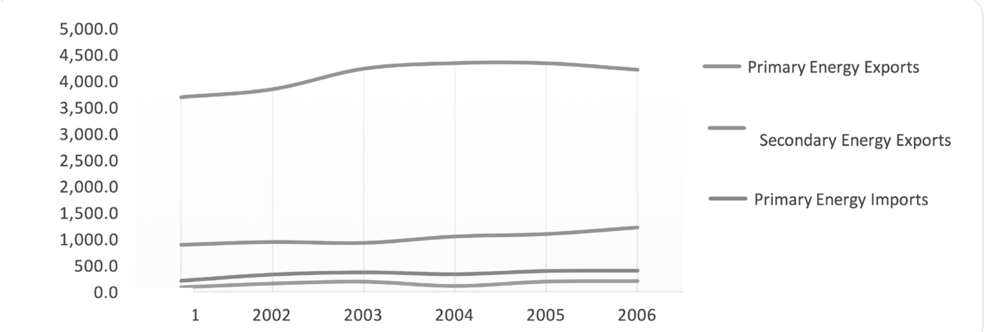

Figura1: Total Imports and Exports by Source 2001- 2006 (PJ)
Source: Own elaboration of Este Pais, 2008.

The above information is relevant if you consider that Mexico consumes mainly secondary energy, and that this is fundamentally based on the consumption of petroleum. According to the figures presented in the *Secretaría de Energía* (Secretariat of Energy (2013)) and based on the figures of the *Instituto Nacional de Geografía e Informática* ([INEGI],2012) (National Institute of Statistics and GeoFiguray) "the energy destined for transformation is on the rise, mainly that of crude oil[4], whereas the volume of extraction has decreased[5], representing a great

[4] Went from 3,061 Petajoules in 2006 to 2,727.66 in 2011.
[5] Approximately 2.5 million barrels daily.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

technical and economical challenge. Between 2000 and 2004, the production of petroleum increased until reaching its maximum level, and started to decline. Regarding final products, Mexico has become a net importer. In addition, the same secretariat presented a consumption of 48.19% during 2010, with regard to the total consumption of power in the country (SENER, 2013, p.4). Which also shows at an internal level the importance of the transport sector and the need to generate a change with regard to the procurement, use, and regulation. Martinez (2012) shows in their investigation that, in Mexico, the contamination derived from the transport sector in certain zones, particularly of high demoFiguraic or industrial density, is grave (p. 4). "Additionally, Mexico faces high health costs" (SENER, 2013, p. 4).

Renewable energies, the energy reform and the institutional changes in Mexico. "It is projected that bioenergy and biofuels especially play an important role in the achievement of the long-term policy and the reduction of CO_2 and in the contribution of the sustainability of the energy supply" (Bellarby, Wattenbach & Gill, 2010, p. 1935). In light of this possibility and opportunities, there are also certain concerns due to the fact that a great portion of the supply and current use of the energy is based on limited resources of fossil fuels, which is unsustainable" (International Atomic Energy Agency [IAEA], 2008, p. 1). Mexico has started establishing changes and strategies in order to strengthen its sector, *La escuela de Graduados en Administración y de Dirección de Empresas* ([EGADE], (2014), mentions that "since 2008, there are already mechanisms in Mexico that have helped develop the budding development of the industry" (p. 22). The idea of national energetic transition is not new, it is still developing but at a very slow pace and with problems and hesitation, this is how Dorantes presents it (2008). It is within this strategy that the Mexican Center of Innovation and Energy have been created, which seek to gather specialized human resources and thus help strengthen the investigation (EGADE, 2014, p.3). It also mentions that Mexico is at a key moment to both redefine its energy reform and to consolidate its measures (p. 7). The researcher from the *Instituto Mexicano para la Competitividad* (The Mexican Institute for Competition (IMCO)), Quiroz (2014), mentions that the "reform includes, among other matters, the adaptation of the legal framework for the environmental protection and the creation of an *Agencia Nacional de Seguridad Industrial y de Protección al Medio Ambiente del Sector Hidrocarburos"* (Agency for the National Industrial Safety and Protection of the Environment in the Sector of Hydrocarbons) (p. 52).

According to the data presented by Aguirre, Gallegos & Pérez (2015), on the extensive evaluation of 200 entrepreneurs, as well as workshops with academy experts, financial institutions and the private sector, it was determined that the sector of clean energy is at its initial stage, even more so if we compare it with that of countries from the OECD, as is shown in the following table:

Table1
Evaluation of the Clean Energy in Mexico

INOVATION	*LEVEL*	*TRADING*	*SCORE*
Investment in I& D	Low	Investment in the scalability stage	Inexistente
Patenting Cleantech	Average	Outflows successful and recovery investments	Low
Human resources	Average	Level of the conglomerates	Inexistente
competitive advantages use	Low	Levels of internationalization	Low

Source: Own elaboration of Aguirre, Gallegos & Pérez, (2015).

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

Types of biomass and generation of biofuels. "Biomass is the fourth source of energy in the world[6], 78% of renewable energy in 2005" (Demiral *et al*., 2011. p. 1). At the time of selecting the raw matter with which the biofuel is going to be elaborated, it is important to take into consideration the provisions of Groom, Gray & Townsend (2008) and those of Annie (2006) to evaluate the practices of the use of the land where the raw materials will be cultivated and handled.

Growth, development and expectations of biofuels. Furtado (2009) mentions that "the international maker of biofuels is even more reduced and it is mainly destined for the internal market" (p. 7). "The production of bioethanol is even greater than that of biodiesel (94%), as well as its international commerce. However, biodiesel has grown at rather superior rates" (Carriquiry *et al*., 2011, p. 4222). According to the report *"Perspectivas Agrícolas 2010-2019"* (Agricultural Perspectives) presented by the *OECD-FAO* (2010), it is projected that the markets of biofuel will be heavily influenced by the mandates and consumption incentives of the countries throughout the world; USA and the EU, respectively, will participate in a meaningful way (p. 102). "In Latin America the largest producer of biofuel will continue to be Argentina, which will represent around 25% of the total biodiesel that is produced in the developing nations and 8% of the world production of biodiesel for 2020" (OECD, 2011, p. 98). According to the OECD (2011), in 2020 more than 75% of the global production of biodiesel will be from vegetable oil, and the one produced from fat, sebum, and waste oils will represent around 15% of the total biodiesel (p.100).

Amount of waste and collection companies in Mexico. Presently, the residue of annual domestic oil is of approximately 6 liters per capita, even though in certain zones it can be of 12 liters. According to the figures presented in Moreno, Vidal, Morgan, Espinosa, & Roblero (2012) and obtained from the database of the INEGI (2013) and the *Procuraduría Federal del Consumidor* ([PROFECO]) (Office of the Federal Prosecutor for the Consumer) the following is presented:

> In Mexico, the per capita consumption is of 2 spoons (ANIAME, 2008). "In this consumption, food absorbs from 15 to 35% and the rest is discarded". (PROFECO, 2013). Regarding the number of existing population, for the annual population and housing census of 2010, a population of 112,336,538 was recorded, which is equivalent to an average of 674,019,228 liters per month. The commercial food establishments also present a great potential for the supply of AVU. At a national level, the INEGI reported that one out of ten establishments sells food, with 353,210 counted establishments (Moreno Vidal, Morgan, Espinosa, & Roblero, 2012, p.896).

According to the data presented by Gasca (2015), Bioenergetics director of the SENER, at the *Foro internacional 2015 de Valorización Energética de Residuos Urbanos,* (2015 International Forum of Energetic Assessment of Urban residues), it has been confirmed that Mexico allocates around 88% of the organic residues to dumpsters and landfills, while less than 5% is used in composts or bio-digestion, and less than 2% in thermal uses, allocating the rest to recycling.

There are different problems created around the production of biofuels from waste, some of the most important are*: The Costs of biofuels,* which is the largest sector in production and goes from 37 to 70% (Coyle, 2007). Authors such as Timilsina & Arshish (2010) handle costs

[6] Around 15% of the global energy power consumption and 38% of the primary power consumption in developing countries.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

that are high and varied, as is the case for cooking oil, which goes from $0.21-0.42 per liter (p. 14); *The sources and access to statistical information:* where the lack of information regarding the commerce of biofuels has promoted the development of investigations" (Heinimo, 2008, p.702). Van Dam & Faaij (2011) mention that "according to the estimations carried out, there is a lack of necessary components and data for the accounting of biofuel at this level". The difficulty to determine the exact volumes is created because raw materials are commercialized for material purposes, but they are used in the production of energy (Hertel & Beckman, 2011) and because the majority of the companies are new (Heinimo, 2008); *The commercial barriers*: as there is no comprehensive commercial regime that applies to biofuels, and that the two more relevant biofuels do not compete at the same level within the *World Trade Organization* (WTO)"[7] (Aristegui, 2009, p. 124). Duffey (2006) & Furtado (2009) state that biofuels such as biodiesel are classified as industrial products and are subject to the general rules of commerce under the WTO[8]. Bioethanol and energy crops, on the other hand, are covered by the Agreement on Agriculture of the WTO[9], and finally; *The societal degree of acceptance:* where the support widely varies according to the technology and the crop[10] (Delshad *et al*., 2011).

Characterization of the investigation

Prior review of the literature (Kerlinger & Lee, 2002; Sierra, 2007; Briones, 2006; Hernández, Fernández & Baptista, 2010), this research is based on the scientific method and presents the following methodological phases:

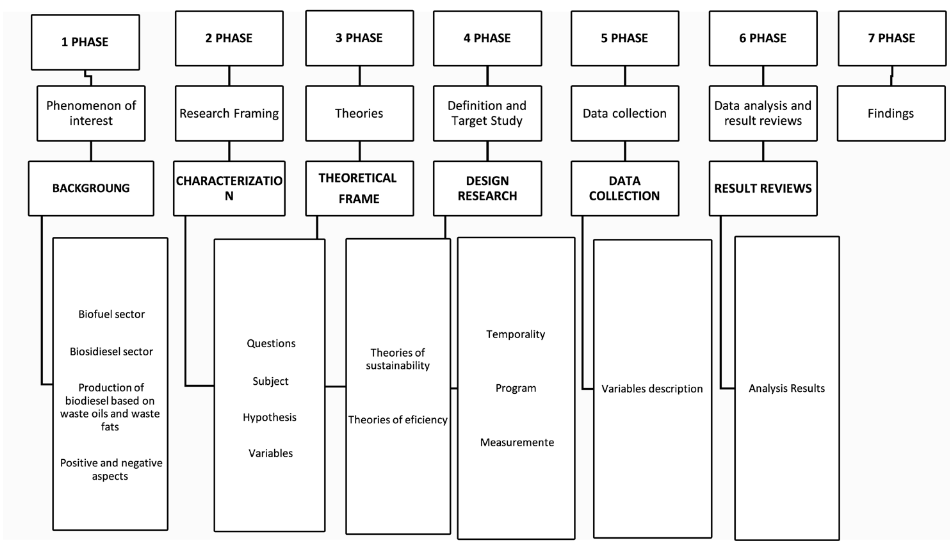

Figure 2: Phases of Research Methodology
Source: Own elaboration, 2016

The research problem is presented as follows: Through the determination of the relative efficiency levels, we can establish a better performance in the decision-making of the operative

[7] While ethanol finds its action framework fundamentally low under the Agreement on Agriculture, biodiesel is subject to the Agreement on Subventions and Compensatory Measures
[8] Fall within chapter 38.
[9] This is part of chapter 22 of the Harmonized System of the WCO.
[10] Biofuels produced from alternative maize cultures, grass and genetically modified cultures are strongly preferred. There is some reservation in the use of trees.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

areas of greater importance in the energetic subsector BAVyGA in Mexico, and with it, improve marketability both in national and international markets.

Once the approach of the problem has been described the *investigation question* is posed: What is the level of relative technical efficiency of Mexican BAVyGA producer companies in relation to the ones presented in Costa Rica, Spain and the United States, when incorporating input and output variables, using the DEA model, which allows for a better orientation in the decision-making of the areas of greater important and with this, improve marketability in both national and international markets?

The *Research objective* entails the following: To determine the level of relative technical efficiency of BAVyGA producer companies in Mexico, in relation to those of Costa Rica, Spain and the United States, incorporating input and output variables, making use of the DEA model to improve the decision-making of the operative areas of greater importance and with this, improve marketability in both national and international markets.

The *Research hypothesis* is presented as the following: The level of relative technical efficiency of the BAVyGAD producer companies in Mexico when using the input and output variables, making use of the DEA model, is inferior to the one found for the companies of Spain and the United States and similar to those of Costa Rica.

Specification of the variables used. The variables taken into consideration: *Input variables: Employees:* which are the people necessary for the production process, and; *Production capacity:* which is the maximum capacity of production of the plant; *Output variables: Liters of biodiesel:* which comprise the amount produced in the previous year. For the approximation of the measuring unit (liters and tons), a necessary condition, it was taken into consideration that the density of the diesel was of 0.88 g/cm^3.

Theoretical framework

Approach of sustainable development. "Sustainable development is one of the most controversial concepts in literature, as more and more elements are being incorporated" (Gallopín, 2003, p. 7). "When the use of the energy sources is examined in terms of production efficiency and minimization of the negative effects on the environment, the concept of clean energy sources appears" (Acaroglu *et al.,* 2011). "At the end of the forties, civil society and academic movements appeared, which questioned the industrialization and development model" (Gutiérrez, 2007, p.55). "But after the second world war, the fast growth of the global economy made it easy to forget, at least in part, the social and environmental aspects" (OLADE & CEPAL, 2003, p. 7). In 1972, with the Stockholm conference, it was acknowledged that the economic development requires an environmental invention. These theses began to spread when the Roma club was created in 1972, which questioned the main thesis of the development theories. "This initial version of the concept was reworked the following year by Sachs in the article "*Environnement et styles de développement*" published in 1974, which describes the concept of eco-development, used to describe a style of development that mainly seeks to satisfy the basic needs and the promotion of autonomy in the populations involved in the process" (Pierri, 2005, pp.48-49). "In the declaration of Coyoco of 1974 and in the report of Dag HammarskjÖld of 1975, the unsustainable growth feature of the population is analyzed. According to the predictions, the threat of environmental catastrophes is evident" (Gallopín, 2003). The term sustainability became popular for the first time in 1987, at the *World Commission*

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

on Environment and Development (WCED), in the Brundtland report, which mentions that "development is not sustained if the base of environmental resources is deteriorated" "Thus, from the participation of the WCED, it is suggested that sustainability can be guaranteed through the accumulation of physical capital that helps compensate the reduction of material" (*Comisión Económica para América Latina* [CEPAL], 2003, p.89). Since 1990 and for the last two decades, the social movements and the production of knowledge coalesced in the diagnosis that says that the theories and the public and private policies for the promotion of development have turned out to be insufficient for the resolution of the sustainable development problems (Gutiérrez, 2007, p.56). At the end of the last century, and in the framework of the project on "Energy and Sustainable Development in Latin America and the Caribbean", it is proposed that the human being should be the active subject and the objective of the development. The CEPAL (203) "mentions that the adopted concept of human being is what is frequently mentioned in the reports of the *United Nations Development Programme* (UNDP) and it is conceived as the process to broaden the range of choice of the people" (p.27). The WCED stated that it is necessary to "emphasize the distributive aspects when classifying as sustainable a development that distributes more equitably the benefits of economic progress, protects the national and global environment for the benefit of future generations" (Pistonesi, Nadal, Bravo, & Bouille, 2008, p. 43). "As a response to the decisions made by the *Commission on Sustainable Development* (CSD) of the United Nations and to the request made in Chapter 40 of Program 21, in 1995 the *United Nations Department of Economic and Social Affairs* (UNDESA) began working to define a set of indicators of sustainable development. At the beginning, the indicators would cover the four main dimensions: social, economic, environmental and institutional" (IAEA, 2008, p. 5). These four dimensions are strongly linked and interact with each other. *In the economic dimension,* sustainability is linked with the possibility of sustaining growth; *In the social dimension* it is important to take care of the quality of life of the population. *In the environmental dimension* it covers a broad range of elements (Pistonesi, pp. 43-44). And *in the political dimension,* it is linked with the governability that pertains to the rights of men (*Organización Lationoamericana de Energía* [OLADE] & CEPAL, 2003, pp. 31-32). "The dimensions must include indicators to evaluate its progress" (Pistonesi *et al*., 2008, p. 48).

Theories and approximations of efficiency. "In microeconomic literature, the term 'efficiency' is defined as the degree of optimization of the resources to obtain what the people need at the lowest possible cost. A production method is considered efficient when, parting from a certain number of factors, you obtain the maximum possible amount of product" (González & Álvarez, 2001). Historically, the design and implementation of efficiency has been different within the economy. In the *macroeconomic* level, efficiency is translated into a country's ability to completely exploit its available resources and obtain its total production (Maldonado, 2008, p.14). Within the *microeconomic* context, the concept of efficiency must be used in relation to the resources used during the production of a company, industry, or sector (Gómez, 2012, p. 31). According to Núñez, Díaz & Martínez (2004), "the study of efficiency between companies arises from the idea to evaluate the behavior of the same, according to the main principle of the microeconomic theory, to maximize its benefits". The origins of this theoretical concept lie on its greatest exponent, Wilfredo Pareto (1848-1923), who reconstructed the theory of consumption and demand on the basis of the usefulness concept of utility. According to this, "efficiency during production requires making the redistribution of inputs impossible in order

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

to obtain the largest amount of product without reducing the production of another product" (Arzubi & Berbel, 2002). In order to descriptively explain this perspective of efficiency, we generally use a Figuraic instrument called the Edgeworth box, which helps analyze the exchange of two goods between two people, Figuraically displaying the preferences of the two through indifference curves. "This problem was brought up again by Debreu, who proposed a radial measure called *Coefficient of resource utilization,* being a ratio with input orientation that establishes the maximum possible equiproportional reduction in all inputs" (Gómez, 2012, p.32). "This ratio quantifies the proportion between the situations obtained in an economy that is moving away from the optimal status" (Romeu & Rodríguez, 2008). "After Kopmans and Debreau, another relevant work was created, which suggested the estimation of technical efficiency in terms of real deviation from the idealized production boundary. The works of these authors were continued by Farell in 1957, who created the conceptual bases that have been the ground of the subsequent methods to measure efficiency" (Galacho, 2010).

Quantification of efficiency. "Methodologically, in order to obtain a measure of efficiency, it is necessary to know the production function or the set of production data that was applied, as well as the efficient boundary" (Guzman, 2005, p. 5). The quantitative estimate that is shown since the work of Farrel, refers the use of convex conical or polygonal shapes to build the isoquants or boundaries in a non-parametric shape, and only on the basis of the information available regarding the behavior of several comparable decision making units (DMUs), many of which, will be more efficient than others (Schuschny, 2007, p.45). Its two great contributions are based on the division of efficiency into two components: *The technical efficiency,* which alludes to the ability to obtain the maximum level of production given the smaller combination of inputs, under the assumption of constant returns to scale (CRS) (Arzubi & Berbel, 2002). This could be measured in terms of physical relations between observable outputs and the maximum attainable output (Herrera & Francke, 2007, p.5). And the second contribution is that of *Allocative efficiency,* which involves achieving the minimum cost of production of a certain quantity of production by changing the proportional relations of the inputs used based on their prices and marginal productivities (Romeu & Rodríguez, 2008, p. 6). Both measures show the economic efficiency (Arzubi & Berbel, 2002, p. 106). With these two possibilities, two ways to estimate the reference boundary were developed: These two groups are those that consider a boundary type function and those that consider the non-boundary type.

Data Envelopment Analysis. The Data Envelopment Analysis (DEA) is a non-linear mathematical programming technique in which the efficient companies unite linearly, comprising an envelopment of production possibilities. "The segment that unites two close efficient companies among themselves constitutes an efficient limit with an input or output orientation" (González & Álvarez, 2001). "Otherwise, a negative evaluation of any of them could depend on external factors" (Arzubi & Berbel, 2002, p. 107). The information obtained through the implementation of the DEA model mainly references four aspects, the likes of which are described by Fernández & Flores (2005): *The efficiency indicator*, which reveals if an analyzed unit is or not efficient; *The gaps*, which signal the quantities of inputs and outputs to decrease and increase; *The efficient units*, which are taken as reference points, and to which the non-efficient units must approximate; *The coefficients*, which signal the importance of each indicator in the determination of efficiency (p. 4). The fact that one DMU is part of the limit

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

does not mean that the entity has obtained its maximum efficiency, but it does indicate that the remaining units can improve their performance (Fernández & Flores, 2005).

Mathematical development of the DEA, BBC, and CCR model. "The *Constant Returns to Scale* (CRS) model was made known in 1978 with the publication made by Charner, Cooper and Rhodes, reason for which it is known as the CCR model, based on the doctoral thesis presented by Rhodes, which was subsequently expanded on by Banker, Charnes and Cooper in 1994, i.e., the *Variable Returns to Scale* (VRS) (BCC model)" (Gómez & Pascual, 2010). "Both in the *CRS* as well as the *VRS* versions, the efficiency can be characterized in relation to two basic orientations: *The oriented output models*, which seek the maximum proportional increase of the outputs while remaining within the limit of production possibilities; *The oriented input models*, which seek the maximum proportional decrease in the inputs while remaining within the limit" (Gómez, 2012, p. 70).

Constant Returns to Scale (CRS) model. Among the hypothesis of this first analysis is convexity, the production technology with CRS, and the orientation towards the maximization of the use of the productive resources (Schuschny, 2007). Hereunder we develop the model according to Herra & Francke (2007) & Sanueza (2003).

Output orientation: The mathematical representation of the accorded model assumes a sample of Decision Making Units (DMUs) such that each *DMUj (j=1,2,3...n)* produce *s* outputs *Yrj (r=1,2,3...s)* using *m* inputs *Xij (i=1,2,3...m)*. The *DEA-CRS* output oriented model expressed in a fractional form is formulated through the following equations:

$$Min\ h(u,v) = \frac{\sum_{i=1}^{m} vixi0}{\sum_{i=1}^{s} uryr0}$$

(1) CRS Model, output orientation, fractional form

$$\text{s.a} \quad \frac{\sum_{i=1}^{m} vixij}{\sum_{i=1}^{s} uryrj} \geq 1 \ ;$$

$$vi, ur \geq 0$$

$$j=1,\ldots,n; \quad r=1,\ldots,s; \quad i=1,\ldots,m$$

The sub-index represents the evaluated unit. The optimal weights *(u*r, v*i)*, problem solution, will differ from one entity to another, as the model is resolved for each entity. The efficiency coefficient of the unit is given by *1/h*0*. If the optimal solution is *h*0=1*, this will indicate that the entity being assessed is efficient in relation to the other entities. If the index is greater than one, the unit being assessed is inefficient. In this case, the entities that, with the same weights *(u*r, v*i)* as those of the inefficient entity that is being evaluated, turn out to be efficient, constitute the efficiency benchmark of the inefficient unit. This factorial program can transform into a linear program in order to facilitate its resolution. To this end, the numerator of the function is maximized while maintaining the denominator constant.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

$$Min\ h(u,v) = \sum_{i=1}^{m} vi\, xi0$$ (2) CRS Model , output orientation, linear Program

$$s.a \quad \sum_{i=1}^{s} ur\ yrj = 1$$
$$\sum_{i=1}^{m} vixij - \sum_{i=1}^{s} uryrj \geq 0$$
$$Vi, ur \geq 0$$
$$j=1,\ldots,n; \quad r=1,\ldots,s; \quad i=1,\ldots,m$$

The linear program selects the weights that minimize the virtual input of the assessed unit *(Vi Xi0)* conditioned so that its virtual output *(ur yro)* is equal to the unit, so that the implementation of said weights to the rest of the decision-making units being assessed does not allow their virtual output to exceed the virtual input. The unit shall be efficient if its virtual input is the unit. In practice, calculating the efficiency indexes is simpler if the dual form of the aforementioned model is used, through which a linear approximation is built in sections to the true limit. The dual formulation is the following:

$$Max\ \varphi$$
$$j=1n\lambda j\ Xij \leq Xi0 \qquad i=1,\ldots,m$$ (3) CRS DEA dual form model
$$j=1n\lambda jYrj \geq \varphi.\ Y\ r0 \qquad r=1,\ldots,s$$
$$\geq 0 \qquad j=1,\ldots,n$$

In this case, $\varphi = 1$ if the assessed unit is considered efficient, as there is no other that produces more or that achieves the same level of production with less resources than it. With this DEA analysis it is also possible to detect likely decreases in the inputs or increases in the outputs can also be detected through the incorporation to the dual model of the so called slack variables. Therefore, it is possible that it does not meet the Pareto-Koopmans efficiency condition, which is more restrictive than that of Farrel, according to which an entity is efficient if and only if $\varphi^* = 1$ and all the slacks are zero, otherwise the entity is evaluated as inefficient. Concretely speaking, for the inputs these slacks represent the additional quantity that each producer could save in the use of the same inputs in the case of being efficient, whereas for the outputs it is identified by how much the production could increase if it were to reach an efficient behavior. These slack variables can be included with the following expressions:

$$j=1n\lambda jYij)\ ;\quad S^+r = (j=1n\lambda jYrj) - \varphi.\ y\ r0$$ (4) Slacks

Where $s\ \bar{\imath}$ represents the input excess i and $S^+ r$, the lack of the r output. Therefore, the dual model (of output maximization) is the following expression:

$$i=1m\ \ s\ \bar{I}\ + r=1s\ \ S+r$$ (5)) CRS DEA Dual form model, optimization

$$j=1n\lambda jXij + s\ \bar{\imath} = Xi0 \qquad i=1,2,\ldots,m$$
$$j=1n\lambda j\ yrj) - S+r = \varphi.\ y\ r\ 0 \qquad r=1,2,\ldots,s$$
0

Where φ is the efficiency index, λi are the weights and $s\ \bar{\imath}$ and $S + r$ are the slack variables of the inputs and outputs, respectively. In this case, a DMU is relatively efficient if and only if its efficiency index is equal to the unit and all the slacks are null. With this formulation of the program, in addition to assigning an efficient index to each evaluated unit, a value is obtained that reflects the *inefficiency* in the use of each input or in the procurement of each output. This information is much more complete than the one offered by the efficiency index and thus it can be of great use when it comes the time to identify the origin of possible inefficiencies on behalf of the producer. At a practical level, one of the DEA results that could perhaps be of greater interest consists in obtaining, for any inefficient entity, a *projection point (X0,*

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

Yo) on the efficient limit that represents an efficient unit (real or virtual), which, in an output oriented model, shall produce, at least, the φ proportion of the outputs of the assessed unit and shall consume, at most, the same quantity of inputs. The referred projection point shall be given by $X\,0 = \Sigma^{n}_{j=1}\, \lambda_{*}j\, Xj$; $Yo = \Sigma^{n}_{j=1}\, \lambda j\, Xj$, i.e., the efficient quantity resulting from the projection is obtained as a linear combination of the observed points, that is, of other entities, which is said constitute the benchmark of the entity evaluated and qualified as inefficient. Knowing the coordinates of the inefficient entity's projection on the limit, it is possible to determine two important results: *its target values* (input and output) and *the potential improvement* that ought to be promoted. The *target values* are the input and output levels that, in case of reaching them, would transform an inefficient entity into an efficient one. The *potential improvement*, in absolute or relative terms, is obtained when comparing the values observed for the evaluated entity with its target values, and allows establishing the amount of the input decrease and/or output increase that this should promote in order to become efficient. In turn, the potential improvement of an entity can be deconstructed into proportional improvement (radial reduction) and slack improvement (slack reduction). Determining the benchmark and the target values of an inefficient entity, it is also interesting to be able to know to what degree each of the *benchmark* units contribute to the aforementioned values. This information expresses the most or least importance that, in each input and output variable, the benchmark represents for the inefficient entity. The potential improvement, in absolute or relative terms, is obtained when comparing the observed values for the evaluated entity with its target values, and allows establishing the amount of the input decrease and/or output increase that it should promote in order to become efficient. Determining the benchmark and the target values of an inefficient entity also results rather interesting in order to know in what measure each of the benchmark units contribute to these. The contribution percentage of the efficient entity k to the objective values of the *r* output of an inefficient unit ($PC_{k,\,r}$) will be given by:

$$PC_{\,k,r} = 100\,\frac{\lambda rkYrk}{\sum_{j=1}^{n} \lambda{*}j\; y\; rj}$$

(6) The contribution percentage of the efficient entity to the objective values

So that the contribution percentage of the efficient entity k to the target values of input i of an inefficient entity ($PC_{k,\,i}$) will be:

$$\mathrm{PC}_{\,k,r} = \frac{100\,(\lambda ikXir)}{\sum_{j=1}^{n} \lambda{*}j\;X\;ij}$$

(7) The contribution percentage of the efficient entity k to the target values of input

Variable Returns to Scale (VRS) model

Assumes the productive process of the company under the long-term time horizon.

Orientation output: The models seen above, are models that allow measuring the purely technical efficiency, eliminating the influence that the existence of economies of scale could have. The measurement of the efficiency of a unit could be conditioned not only by the management of the same, but also by the scale in which it operates, whereas the aforementioned models assume the CRS model. Banker, Charnes and Cooper, proposed as a solution to said implicit consideration adding an additional restriction to the CRS model so as to limit the search of DMU comprised more efficiently in the convex envelope defined by the DMUs, with which the comparison between DMU with similar characteristics is carried out.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

$$Max\ h(u,v) = \sum_{r=1}^{s} UrYr0 + \mu$$ **(8)** **VRS Model, fractional output orientation**

$$s.a \quad \sum_{r=1}^{s} VrYrj - \sum_{i=1}^{m} UiXij + \mu \leq o; \quad j = 1, L, n$$ **(9)** **VRS Model, increasing returns**

$$\sum_{r=1}^{s} UrYrj = 1 \qquad j: 1,\dots, n$$ **(10)** **VRS Model, constant returns**

$$Vr, ui \geq 0 \qquad j: 1,\dots, n$$ **(11)** **VRS Model, decreasing returns**

$$\mu \ \ libre$$

In this last model the optimal, μ, indicates the possibilities of returns to scale in which the unit finds itself. "$\mu \leq 0$ suggests that the evaluated unit is operating with growing returns to scale; $\mu \geq 0$ suggests that the unit is under decreasing returns and, finally, $\mu = 0$ indicates that it is operating under CRS" (Sanhueza, 2003, p. 89).

Investigation design

Time, spatial and sectoral delimitation of the sample. This study analyzes the situation of 30 manufacturing companies of biodiesel derived from vegetable oils and waste animal fats in 2014, of 4 countries: Costa Rica, United States of America, Spain, and Mexico. Same that showed availability to provide data through our survey or own databases and/or of associations. Which are shown in the following table.

Table 2
Manufacturing companies of BAVGA

Costa Rica			-
Cooperativa Agrícola Industrial Victoria	Energías Biodegradables		
Mexico			
Combustibles Biológicos de México	Moreco	Renovables Maya Verde	
Spain			
Biodiesel Castilla-La Mancha	Bio Bionet Europa, S.A.	Bionor Transformación, S.A.	Bionorte
Grupo Ecológico Natural, S.L.	Stocks Del Valles, S.A.	Ecofuel	Energética Española
United States			
Baker Commodities Los Angeles	Bay Biodiesel, LLC (San Jose)	Biodiesel Industries of Ventura, LLC	BioDiesel One Ltd
Bridgeport Biodiesel, LLC	CGF Clayton LLC	Community Fuels	Crimson Renewable Energy, LP
Delta American Fuel, LLC	FL Biofuels, LLC	Genuine Bio-Fuel	GeoGreen Biofuels, Inc.
Healy Biodiesel	Imperial Western Products	Iowa Renewable Energy, LLC	Middle Georgia Biofuel
New Leaf Biofuel, LLC			

Source: Own elaboration from databases, 2014.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

Model specifications. To identify the assumptions on which the proposed model is based, what was proposed by Romeu & Rodríguez (2008) is established and summarized: Measurement of technical efficiency: *DEA Analysis*, given the ease of use of the variables and results; Orientation of the efficiency measurement: *Output*, since the production levels are low, it is intended to maximize the product; Typology of returns to scale: *Growing and Variable*, based on first determining if the companies are operating at optimal scale.

Data collection

Notation of the Variables and DMUS: There were a total of 20 DMUs used, which acquire the following notation:

Table 3
Notation of the DMUs used

Costa Rica	Coopavi
1.-Cooperativa Agrícola Industrial Victoria	Enerbio
2.-Energías Biodegradables	
Mexico	
3.- Combustibles Biológicos de México	Combiomex
4.- Moreco	Moreco
5.- Renovables Maya Verde	Remave
Spain	
6. - Biodiesel Castilla-La Mancha	Biocama
7.- Bio Bionet Europa, S.A	Biobionet
8.- Bionor Transformación, S.A.	Bionor
9.- Bionorte	Bionorte
10.-Grupo Ecológico Natural, S.L.	Grenatura
11.-Stocks Del Valles, S.A._	Stockva
12.-Ecofuel	Ecofuel
13.-Bioenergética Española_	Bioenergética
The United States	
14.-Baker Commodities Los Angeles	Backmoan
15.-Bay Biodiesel, LLC (San Jose)	Baybio
16.-Biodiesel Industries of Ventura, LLC	Bioventura
17.-BioDiesel One Ltd Bridgeport Biodiesel, LLC	Bioneltd
18.-Bridgeport Biodiesel LLC	Bridgeport
19.-CGF Clayton LLC Community Fuels	Cfgclayton
20.-Community Fuels	Communityfuel
21.-Crimson Renewable Energy, LP	Crimsonrenew
22.-Delta American Fuel, LLC FL Biofuels, LLC	Deltamerican
23.-Fl Biofuels LLC	Flbiofuellc
24.-Genuine Bio-Fuel	Genuinebiofuel
25.-GeoGreen Biofuels, Inc.	Geogreen
26.-Healy Biodiesel	Healybio
27.-Imperial Western Products	Imperialwest
28.-Iowa Renewable Energy, LLC	Iowarenewa
29.-Middle Georgia Biofuel	Middlegeorg
30.-New Leaf Biofuel, LLC	Newleaf

Source: Own elaboration from databases, 2014.

The notation for the output variable and the two input variables are:

Table 4
Notation for the variables

Variable	*Indicator*	*Notación*
Input	Production Level	Nivelprod
Output	Employees Production Capacity	Empleado Capacidprod

Source: Own elaboration 2016

Analysis of the results

Descriptive statistics. There is a minimum of three *employees* for Biodiesel Industries of Ventura, LLC. Whereas the maximum level of employees is held by Imperial Western Products, both based in California. The *annual production capability* oscillates broadly, from the 400 tons a year in the Mexican company Renovables Maya Verde, up to the 416,000 tons in the case of CGF Clayton LLC, situated in Delaware. For the case of the *annual production* this goes from 60 tons in the case of Combustibles Biológicos de México, up to the 350,000 tons with Delta American Fuel, LLC.

Table 5
Descriptive statistics

Nombre	***Minimum***	***Maximum***	***Average***	***Standard Deviation***
Empleado	3	50	15.666	45.964
Inve&Des	0	4	0.933	0.891
Capacidproduc	400	416000	82874.9333	117528.2264
Nivelproduc	60	350000	53, 600.2	85482.1278
Preciobiodie	1.05	1.22	1.093	0.066
Gamaproduct	1	3	1.666	0.649
Pobmun	476	10017068	956088.4	2017285.752
Destino	0	1	0.766	0.423
Formcomerc	0	1	0.166	0.372
Preciodies	0.961	1.64	1.152	0.294
Impuestodie	0.009	0.413	0.222	0.128
Progra&apoyo	0	1	0.133	0.339

Source: Own elaboration from the Data Envelopment Analysis Online, 2014.

DEA (CRS and VRS) efficiency analysis, incorporating employees and production capability. Contemplating that these are mainly medium-size and growing companies, the values of the efficiency indexes under VRS that measure the comparative ETP level, since it excludes the effects of scale, are greater than the corresponding values under CRS, which measure the ETG level. This would indicate that the countries do not operate at the most efficient scale. For most companies, the difference in the levels of efficiency is lower than 6%.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

However, for the company Bioenergetica the difference is of 9%, in Moreco of 36%, and in the case of the company Remave it is of 63%. Furthermore, it can be generally observed for both cases that the North American companies are leaders in levels of efficiency. Hereunder, the results of the analysis of efficiency to scale are shown (ETG/ETP).

Table 6
Measuring efficiency scale

	DMU	*ETG*	*ETP*	*EE*
1	Imperialwest (EU)	100%	100%	100.0%
2	Middlegeorg (EU)	100%	100%	100.0%
3	Communityfuel (EU)	99.5%	100%	99.2%
4	Crimsonrenew (EU)	99%	100%	99.2%
5	Iowarenewa (EU)	96%	96%	100.0%
6	Deltamerican (EU)	93%	94%	98.9%
7	Healybio (EU)	92%	97%	94.8%
8	Bioneltd (EU)	92%	95%	96.8%
9	Geogreen (EU)	92%	99%	92.9%
10	Backcoman (EU)	91%	92%	98.9%
11	Bionorte (Es)	91%	97%	93.8%
12	BayBio (EU)	90%	91%	98.9%
13	Flbiofuellc (EU)	88%	91%	96.7%
14	Genuinebiofuel (EU)	86%	88%	97.7%
15	Bionor (Es)	86%	89%	96.6%
16	Bridgeport (EU)	80%	83%	96.4%
17	Bioventura (Es)	80%	100%	80.0%
18	Newleaf (Es)	80%	81%	98.8%
19	Grenatura (Es)	76%	76%	100.0%
20	Biobionet (Es)	76%	77%	98.7%
21	Stockva (Es)	66%	69%	95.7%
22	Moreco (Méx)	57%	93%	61.3%
23	Biocama (Es)	50%	51%	98.0%
24	Cfgclayton (EU)	48%	100%	48.0%
25	Enerbio (CR)	40%	42%	95.2%
26	Remave (Mex)	33%	100%	33.0%
27	Coopavi (Es)	33%	37%	89.2%
28	Ecofuel (Es)	25%	25%	100.0%
29	Bionergetica (Es)	13%	22%	59.1%
30	Cambiomex (Mex)	3%	4%	75.0%

Source: Own elaboration from the Data Envelopment Analysis Online, 2014.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

A value below 100% for the majority of countries means that the majority of countries has not been able to reach the maximum level of efficiency (in comparative terms) as it is not operating in the most productive scale it otherwise could. Only the companies Middle Georgia and Imperial Western of the USA have reached a 100% efficiency level with economies of scale. Given the aforementioned results, we proceeded to evaluate each of the previously established variables for the DEA model, using the VRS model. Thus, among the results of the analysis of efficiency incorporating only variables of scale, a Mexican company be found "Renovables Maya Verde". The American companies "Biodiesel Industries of Ventura LLC, Community Fuels, Crimson Renewable Energy, LP, Imperial Western Products, CGF Clayton LLC, Iowa Renewable Energy, LLC, and Middle Georgia Biofuel". The first four being from the State of California, whereas the last three are from Delaware, Iowa and Georgia, respectively. There are also companies shown with a high level of efficiency, with levels close to the unit. In the case of the American companies, it is shown that all the remaining ones are close to the level of efficiency. In the case of Mexico, the company "Moreco" from the state of Michoacán also has a high level of efficiency. And in the case of Spain the companies "Bionor Transformación" and "Bionorte" of Álava and Asturias, respectively, are companies with a high level of efficiency. The companies with low levels of efficiency are: Cooperative Agrícola Industrial Victoria, from Alejuela Costa Rica; Cambiomex, Mexican company situated in Villa Hermosa Tabasco; Bioenergética Española a company established in Zaragoza, and Ecofuel also from Spain. The main **Slacks** showed the underutilization of the input variables that allow obtaining higher levels of production. The main ones were: Cooperative Agrícola Industrial Victoria from Ajuela, with an excess of more than four employees. Whereas Stocks Del Valles, S.A. had an excess of 36 employees. In the Spanish company "Bioenergética Española), there is an excess or waste in the productive capability of 22,800 annual tons.

Tabla 7
Slacks

DMU	*Eempleado*	*Capacidprod*	*Nivelprod*
Coopavi	4.12	0	0
Enerbio	2.675	0	0
Moreco	1.783	0	0
Bionergetica	0	22800	0
Stockva	36.373	0	0
Baybio	0.627	0	0
Iowarenew	11.59	0	0

Source: Own elaboration from the Data Envelopment Analysis Online, 2014.

The **Improvements** showed that for the case of Stock del Valle, large reductions were done with regard to the number of *employees* that it must include from having close to 45 to a recommended level of eight. And in the case of Iowa it is recommended to reduce the number to around 12 employees; Iowa Renewable Energy, LLC must also reduce its number to around 12 employees, whereas the Cooperativa Agrícola Industrial Victoria almost does it in half, going from 10 to 5.88. Regarding the *production level*, there is also the possibility to increase it for the majority of the companies through the utilization of the installed capacity.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

Table 8
Posibility to increase

DMU	*Empleado*	*Capacidadproduc*	*Nivelproduc*
Coopavi	10 to 5.88	3000 to 3000	1000 to 2726.715
Enerbio	10 to 7.325	5000 to 5000	2000 to 4724.187
Combiomex	4 to 4	2000 to 2000	60 to 1711.201
Moreco	6 to 4.217	700 to 700	400 to 429.621
Remave	4 to 4	400 to 400	130 to 130
Biocama	8 to 8	50000 to 50000	25000 to 49205.264
Biobionet	50 to 50	73860 to 73860	56180 to 73394.139
Bionor	6 to 6	35000 to 35000	30000 to 34352.491
Bionergetica	8 to 8	250000 to 227200	30000 to 224000
Bionorte	5 to 5	5000 to 5000	4550 to 4690.459
Ecofuel	48 to 48	300000 to 300000	75000 to 296419.333
Grenatura	8 to 8	39700 to 39700	30000 to 39026.28
Stockva	45 to 8.627	6800 to 6800	4500 to 6521.913
Backcoman	80 to 80	120000 to 120000	110000 to 119427.18
Baybio	18 to 17.373	18900 to 18900	17000 to 18606.624
Bioventura	3 to 3	37900 to 37900	30200 to 30200
Bioneltd	5 to 5	11400 to 11400	10500 to 11015.265
Bridgeport	6 to 6	10000 to 10000	800 to 9646.218
Cfgclayton	3 to 3	416000 to 416000	40000 to 40000
Community	49 to 49	75500 to 75500	75000 to 75000.365
Crimsonrenew	20 to 20	113600 to 113600	112200 to 112232.08
Deltamerican	44 to 44	378500 to 378500	350000 to 373697.21
Flbiofuellc	4 to 4	17000 to 17000	15000 to 16534.965
Genuinebiofuel	8 to 8	34800 to 34800	30000 to 34183.85
Geogreen	6 to 6	3800 to 3800	3500 to 3519.063
Healybio	4 to 4	7600 to 7600	7000 to 7245.406
Imperialwestern	250 to 250	340700 to 340700	340000 to 340000
Iowarenewa	44 to 32.41	39700 to 39700	38000 to 39380.341
Middlegeorg	4 to 4	113600 to 113600	112000 to 112000
Newleaf	5 to 5	18900 to 18900	15000 to 18427.146

Source: Own elaboration from the Data Envelopment Analysis Online, 2014.

Thus, for example, in the case of Cooperativa Victoria it is recommended to increase it by 172%. For Cambiomex there is a great installed capacity that could be utilized, thus increasing the capacity up to 28.51 times. In the case of Ecofuel, a Spanish company, there's also the possibility to expand its production up to a 295.2% beyond what it currently produces.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

Bioenergética Española also has the capability of increasing its production by a little over seven times what it currently produces. Finally, Biodiesel Castilla-La Mancha could do so by 96.8%. On the other hand, there are companies that are operating at their maximum production level such as Renovables Maya Verde, Biodiesel Industries of Ventura, LLC, CGF Clayton LLC, Imperial Western Products, and Middle Georgia Biofuel. Whereas some of them have the possibility of increasing their production in a level below 10%, as is the case of Moreco, Bionor Transformación, S.A., Bay Biodiesel, LLC, Community Fuels, Iowa Renewable Energy, LLC, Healy Biodiesel, and Delta American Fuel, LLC. The companies that can increase production in a medium level are Stocks Del Valles, S.A., by 44.9%, Grupo Ecológico Natural, S.L., by 30%, Bridgeport Biodiesel, LLC, can do so by 20.6%, and New Leaf Biofuel, LLC, by 22.84%. The Lambdas allowed for the identification of the degree of benchmarking that must be carried out for each of the companies. The company Renovables Maya Verde of Mexico, Imperial Western Products that has a plant in California and Arizona, and Middle Georgia Biofuel of Georgia are the companies that are best catalogued as companies that can be picked up once more in order to elevate the level of efficiency.

Efficient companies. The following table shows the results that allowed identifying what each company must do.

Table 9
Benchmarking

DMU	*Remave*	*Bioventura*	*Cfgclayton*	*Imperialwest*	*Middlegeorg*
Coopavi	0.992	0	0	0.008	0
Enerbio	0.986	0	0	0.014	0
Combiomex	0.986	0	0	0	0.014
Moreco	0.999	0	0	0.001	0
Remave	1	0	0	0	0
Biocama	0.594	0	0	0.016	0.389
Biobionet	0.726	0	0	0.187	0.087
Bionor	0.711	0	0	0.008	0.281
Bionergetica	0	0.432	0	0	2
Bionorte	0.968	0	0	0.004	0.028
Ecofuel	0	0	0	0.157	2.169
Grenatura	0.685	0	0	0.016	0.298
Stockva	0.981	0	0	0.019	0
Backcoman	0.563	0	0	0.309	0.128
Baybio	0.946	0	0	0.054	0
Bioventura	0	1	0	0	0
Bioneltd	0.911	0	0	0.004	0.085
Bridgeport	0.932	0	0	0.008	0.06
Community	0.704	0	0	0.183	0.114
Crimsonrenew	0.13	0	0	0.065	0.804
Deltamerican	0	0	0	0.129	2.945

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

Flbiofuellc	0.853	0	0	0	0.147
Genuinebio	0.729	0	0	0.016	0.255
Geogreen	0.986	0	0	0.008	0.006
Healybio	0.936	0	0	0	0.064
Imperialwest	0	0	0	1	0
Iowarenewa	0.885	0	0	0.115	0
Middlegeorg	0	0	0	0	1

Source: Own elaboration from the Data Envelopment Analysis Online, 2014.

The company Renovables Maya Verde of Mexico, Imperial Wester Products with a plant in California and Arizona, and Middle Georgia Biofuel of Georgia are the companies classified as the most efficient and could be taken as a reference model.

Conclusions

This investigation shows results that determine the level of technical efficiency relative to the manufacturing companies of BAVyGA of Mexico and offers data for decision-making strategies in their operative areas and thus improves marketability, both in national and international markets. From these determinants, diverse factors and characteristics could be established that indicate the need to improve for the inefficient companies, showing aspects of those companies that are considered efficient, with the purpose of optimizing the production of biodiesel. The results are briefly exposed hereunder: a broad versatility could be observed regarding both the input and output variables, which indicates the size and expansion of each of them, so that efficient and inefficient companies can retake the example of the efficient companies and, in addition, raise their production level. By determining the input variables, employees and capacity, it was determined that the companies are not producing at an efficiency of scale, given the difference found between the ETG and ETP (between the calculated efficiency under CRS and under VRS). Therefore, based on this, we proceeded to carry out an analysis under VRS; i.e., taking into consideration the effects of scale in the production in order to obtain more efficient companies, contemplated as examples to follow, in accordance with the environment in which they develop, these being the North American companies Imperial Western, Middle Georgia, Biodiesel of Ventura LLC, and the Mexican company Renovables Maya Verde. Likewise, small companies that are currently producing in an efficient manner with regard to their productive capability and their number of employees were detected; however, if we consider once more what was presented in the first section of this paper, where it is mentioned that in Mexico the approximate and average residue of the Mexican people is of 6 liters per inhabitant, we see that many companies, even working in an efficient manner, can increase their production. Imperial Western Product, located in the State of California, and which also has a subsidiary in the state of Arizona, shows the clear example to follow of a company that produces biodiesel solely based on waste animal fats and vegetable oils, and is considered rather large given that it goes beyond 100 billion annual tons. Middle Georgia Biofuel, which is also one of the efficient companies to be considered a model, is a small company located in Georgia, utilizes waste vegetable oil and animal fats, and in addition it takes advantage of its forestry resources in order to diversify the products it offers. Biodiesel of Ventura, LLC,

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

is one of the American companies of greatest growth, located in California. This company has managed to benefit from its strategic location in order to produce and commercialize the product, in addition to taking advantage of the support that has been established at both the State and Federal levels.

On the other hand, Renovables Maya Verde, a small-sized Mexican company, has managed to take advantage of its strategic location for the gathering of used vegetable oils and waste animal fats from the area of the Riviera Maya, Tulum and Cancun, given the broad quantity of residues that are produced daily in the hotels and restaurants of the region. Given these finds, it is established that the working hypothesis that affirms that the efficiency level in the production of the manufacturing companies of BAVyGAD in Mexico is below what is found in the companies of Spain and the USA, and similar to those of Costar Rica, when utilizing the input and output variables and making use of the DEA model, which is not valid for all the Mexican companies, as there is a company that, though small, was found to be producing efficiently due to its good utilization and location. Given these results, the possibility is posed that small and medium size companies in Mexico can make use more broadly and in a better form the residues of animal fats and vegetable oils, through a better utilization of their advantages due to location, population and resources, as well as from the implementation of strategies that allow support, link and impulse the gathering, processing and innovation of the proposed bio-combustible, with the help of the governmental sector; just as it has been shown for the North American companies, as well as the Mexican one. The fact of being a recently incorporated subject generates an issue, since the large part of support, projects and existing investigations are fundamentally oriented towards the production of ethanol or, as the case may be, biodiesel based on agricultural matter.

Proposal and recommendations

According to the findings, the following proposals are established for the case of the Mexican companies: ***To establish a support policy management towards the biodiesel sector in Mexico***: it is fundamental to stimulate both the consumer and the producer in the use and generation of sustainable alternative energies throughout the life cycle of the product, as is the case of the North American companies that are strongly backed in this aspect; ***To implement a strategy for residue management and collection:*** this to increase the collection of waste taking advantage of the residues of the population in each region of the Mexican companies; ***To manage the minimum mixture of combustibles in Mexico:*** This is very important given that, as it was analyzed, the mandatory policies have allowed a good development in other countries such as the USA and Spain, so that establishing a minimum mixture implies a minimum consumption of the existing production; ***To create and/or manage research and technological development centers:*** It is necessary to create more research and technological development centers for the production of biodiesel in both governmental as well as educational institutions, that allow for the creating of regulations, standards and advances in quality at a national and international level, and; ***To promote an updated database in the Mexican companies:*** It implies that a good development of the sector must have basic data that allows people and researchers to know about relevant information, such as production, employees, support, etc.

References

Acaroglu, M.& Aydogan, H. (2011, Noviembre 8). Biofuels Energy Sources and Future of Biofuels Energy in Turkey. *Biomass and Bioenergy, 36,* 69 – 76. http://dx.doi.org/10.1016/j.renene.2017.02.008

Aguirre, L.,Gallegos, T., Pinzon, J. (2015). *Cleantech México 2015. Panorama y recomendaciones para impulsar la Ecoinovación Nacional: Enlace Emprendedores Ecoinovación.*

Annie, D. (2006, Septiembre 2). Producción y Comercio de Biocombustibles y Desarrollo Sustentable: Los Grandes Temas. Londres, Inglaterra: Instituto Internacional para el Medio Ambiente y Desarrollo. Recuperado de http://www.iied-al.org.AOP (2007, Noviembre). *Eficiencia Seguridad y Sostenibilidad: Requerimientos para la introducción de los biocarburantes*. España: Asociación Española de Operadores de Productos Petroliferos.

Aristegui, J. (2009, Julio). Los biocombustibles desde la Perspectiva del Comercio Internacional y del Derecho de la Organización Mundial del Comercio. *Revista de Derecho*, *22*(1), 113-134.

Arzubi, A., & Berbel, J. (2002). Determinación de los índices de Eficiencia DEA en las Exportaciones Lecheras en Buenos Aires. *Economía Sociológica y Políticas Agrarias.* Escuela Tecnológica Superior de Ingenieros Agronomos y Montes, *17*(2), 103- 123.

Bellarby, J., Wattenbach, M., & Gill, T. (2010, Julio 23). The Potential Distribution of Bioenergy Crops in the UK Under the Present and the Future Climate. *Biomass and Energy*, 1935-1945, doi: 10.1016/j.biombioe.2010.08.009.

Briones, G. (2006). *Métodos y técnicas de Investigación para las Ciencias Sociales* (4ª ed.). México, D.F., México: Trillas.

CAP (2008). *Situación del Sector Biocarburantes en Andalucía: Perspectvas y Desarrollo.* Andalucía, España: Junta de Andalucía, Consejería para la Agricultura y la Pesca. ISBN: SE-645-08.

Carriquiry, M., Xiaodong, D., & Timilsina, G. (2011, Mayo 6). Second Generation Biofuels: Economics and Policies. *Energy Policy, 39,* 4222-4234. https://doi.org/10.1016/j.enpol.2011.04.036

Case, K. E., & Fair, R. C. (2001). *Principios de Microeconomía (4ª ed.).* Mexico, D.F.: Prentice Hall.

CEPAL. (2003). *Energía y Desarrollo Sustentable en America Latina y el Caribe: Guía para la Formulación de Políticas Energéticas* (Primera ed.). Santiago de Chile: CEPAL.

CNE. (2012, Marzo 8). *Análisis comparativo de los sistemas nacionales de sostenibilidad de los biocombustibles y bioliquidos en la UE*. España: Comisión Nacional de Energía. Recuperado de http://energia.cnmc.es/cne/doc/publicaciones/cne08_12.pdf

CMMAD (1987). *Informe de la Comisión Mundial sobre el Medio Ambiente y el Desarrollo*: *Nuestro Futuro Común. 1987*. España: Alianza Editorial, 21 -45.

Coyle, W. (2007). The Future of Biofuel: A Global Perspective. *Feature. USDA*, *5*(5), 24-29.

Delshad, A., Raymond, L., Sawicki, V., & Wegener, D. (2011, Marzo 11). Public Attitudes Toward Political and Technological Options for Biofuels. *Energy Policy, 38,* 3414–3425. http://dx.doi.org/ 10.1016/j.enpol.2010.02.015.

Demiral, I., Eryaz, A., & Sensoz, S. (2011, Noviembre 17). Bio-oil Production from Pyrolysis of Corncob (Zea mays L.). *Biomass and Bioenergy, 36,* 43 - 49. *doi: 10.1016/j.biombioe.2011.10.045*

Demirbas, A. (2011, Agosto 17). Competitive Liquid Biofuels From Biomass. *Applied Energy, 88,* 17-28. http://dx.doi.org/10.1016/j.apenergy.2010.07.01.

Dorantes, J. (2008, Septiembre). *Las Energías Renovables y la Seguridad Energética Nacional.* México, D.F.: AI México. Recuperado de: http://www.ai.org.mx/ai/archivos/coloquios/5/Las%20Energias%20Renovables%20y%20la%20Seguridad%20Energetica%20Nacional.pdf

Duffey, A. (2006, Septiembre). *Producción y comercio de biocombustibles y desarrollo sustentable: los grandes temas, Instituto Internacional para el Medio Ambiente y Desarrollo.* Londres: El Instituto Internacional para el Medio Ambiente y Desarrollo. Recuperado de http://pubs.iied.org/pdfs/15504SIIED.pdf

EGADE, B. S. (2014). *Energías renovables para la competitividad en México.* Instituto Global para la Sostenibilidad. Recuperado de http://static1.squarespace.com/static/54fe1c8ce4b0471d2f7400cd/t/54ff9856e4b0dd225d-6fb098/1426036822946/Factsheet_IGS_2015-ESP.pdf

FAO, O. (s.f.). *Perspectivas Agricolas 2011-2020.* Obtenido de http://dx.doi.org/10.1787/agr_outlook-2011-es

FAO, O. (2010). *Perspectivas Agricolas 2011-2020.* Obtenido de http://dx.doi.org/10.1787/agr_outlook-2011-es

Fernández, Y., & Flores, R. (2005). Aplicación del Modelo DEA en la Gestión Pública. Un análisis de la Eficiencia de las Capitales de Provincias Españolas. *Universidad de León.*

Furtado, A. (2009, Abril). *Biocombustibles y Comercio Internacional: Una persp*ectiva Latinoamericana. Unidad de Recursos Naturales y Energía de la División de Recursos Naturales e Infraestructura. Documento presentado en el marco del proyecto "Modernization of the State, productive development and sustainable use of natural resources" Santiago de Chile: CEPAL.

Galacho, C. (2010). La Medida de la Efciencia Técnica de los Gupos de investigación del Área de Economía de la Universidad de Málaga.*Cuaderno de Ciencias Económicas y Empresariales*, *32*.

Gallopín, G. (2003). Sostenibilidad y Desarrollo Sostenible: un enfoque sistemático. Medio Ambiente y Desarrollo, 63. Recuperado de: http://repositorio.cepal.org/bitstream/handle/11362/5763/S033120_es.pdf?sequence=1.

Gasca, S. (2015, Octubre 7). *Foro Internacional 2015. Valorización Energética de Residuos Urbanos: Experiencias Globales*. México: D.F.

Gómez, J. (2012, Mayo). *Eficiencia y Diversificación: Sector de Caja de Ahorros* (Tesis de Doctorado). Facultad de Economía y Empresa, Universidad de Murcia. Murcia, España. Recuperado de https://digitum.um.es/xmlui/bitstream/10201/28510/1/Eficiencia% 20y%20Diversificaci%C3%B3n.%20Autor_Juan%20C%C3%A1ndido%20G%C3%B3mez%20Gallego.pdf

González, F., & Álvarez, P. &. (2001). Análisis no Paramétrico de Eficiencia en Explotaciones Lecheras. Oviedo, España: *Departamento de Economía, Universidad de Oviedo.*

Groom, M., Gray, E., & Townsend, P. (2008, Noviembre 13). Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production. *Conservation Biology, 22* (3), 602-609. http://dx.doi.org/ 10.1111/j.1523-1739.2007.00879.x.

Gutiérrez, E. (2007, Diciembre). De la Teoría del Desarrollo al Desarrollo Sustentable. *Trayectorias, 9*(25), 21- 35. Recuperado de: http://www.redalyc.org/pdf/607/60715120006.pdf.

Guzman, I. (2005,). *Predicción de Resultados Empresariales Versus Medidas no Paramétricas de Eficiencia Técnica: Evidencia para Pyme de la Región de Murcia.* Trabajo presentado en VII Reunión de Economía Mundial, Cartagena. España. Recuperado de http://repositorio.bib.upct.es/dspace/handle/10317/856

Heinimo, J. (2008). Methodological Aspects on International Biofuels Trade: International Streams and Trade of Solid and Liquid Biofuels in Finland. *Biomass and Bioenergy, 32*, 702 - 71 6, *doi:10.1016/j.biombioe.2008.01.003*

Hernández, R., Collado, C., & Baptista, P. (2010). *Metodología de la Investigación* (5a ed.). México, D.F.: Mc Graw Hill.

Herrera, P., & Francke, P. (2007, Febrero). Un análisis de la Eficiencia del Gasto Municipal y sus Determinantes. *CIES*, *Pontifica Universidad Católica del Perú* .

Hertel, W., & Beckman, J. (2011, Febrero). Commodity Price Volatility in the Biofuel Era: and Examination of the Linkage Between Energy and Agricultural Markets. *Biomass and Energy,* 16824, 278- 289, *Recuperado de http://www.nber.org/papers/w16824*.

IFQC (2006, Abril).Market and Publicy Developments Quality, Standars & Handling.Metanol Institute.

INEGI (2012). El Sector Enrergético en México: Series sectoriales. Recuperado de: http://internet.contenidos.inegi.org.mx/contenidos/productos//prod_serv/contenidos/espanol/bvinegi/productos/integracion/sociodemografico/Energetico/2012/Ener2012.pdf

Jassen, R., & Damian, R. D. (2011, Enero 25). Sustainability of biofuels in Latin America: Risks and opportunities. Energy Policy, 39(10), 5717–5725. doi:10.1016/j.enpol.2011.01.047.

Kerlinger, F. & Lee, H. (2002). *Investigación del comportamiento: Métodos de investigación en Ciencias Sociales* (4[a] ed.). D.F., México: McGraw-Hill.

http://dx.doi.org/10.22201/fca.24488410e.2018.1068

López, J., Henao, S., Morales, M. (2007, Diciembre). Aplicación de la técnica dea (data envelopment analysis) en la Determinación de eficiencia de centros de costos de producción. *Scientia and technica, Universidad Tecnológica de Pereira. 37*(7).

Maldonado, M. (2008, Diciembre). Una Aproximación a la Eficiencia Técnica del Gasto Público en Educación en las Regiones de Perú. *Consorcion de Investigacón Económica y Social.*

Montiel, J. (2010, Abril). Potencial y Riesgo de los Bioenergéticos en México. *Red de Revistas Cientificas de América Latina, Estudios de Economá Aplicada, 6*(1), 57- 62.

Moreno, E., Vidal, J., Morgan, C., Espinosa, M., & Roblero, I. (2012, Junio). Aceites Reciclados de Cocina como Materia Prima de Proxima Generación para la Obtención de Biodiesel en Chiapas. *Concyteg*, 85(7), 895- 910.

Nuñez, M., Diaz, L., & Martínez, C. (2004). Estudio de la Eficiencia de las Empresas de la Cadena de la Madera en la Comunidad de Madrid. *Cuaderno de Ciencias Sociales de España*, 18(1), 115- 120.

OCDE. (2013). *Evaluaciones sobre el Desempeño Ambiental en México.* OCDE. Recuperado de http://www.oecd.org/fr/env/examens-pays/EPR%20Highlights%20MEXICO%2020 13%20ESP.pdf

OCDE-FAO. (2010). *Perspectivas Agricolas 2010-2019*. OCDE-FAO. *http://dx.doi.org/10.1787/agr_outlook-2011-es*

OIEA (2008, Julio). Indicadores Energéticos del desarrollo sostenible: directrices y metodologías. Viena, Austria: Departamento de Asuntos Económicos de y Sociales de las Naciones Unidas.

OLADE & CEPAL (2003, Diciembre). Energía y Desarrollo Sustentable en América Latina y el Caribe: Guía para la formulación de políticas energéticas. (1ªed.). Santiago de Chile: CEPAL, 11- 56. Recuperado de: http://www.cepal.org/drni/proyectos/energ%C3%ADa/ Manualespanol.pdf

Palomares, R. (2012). Análisis de Eficiencia con Variables Exógenas Categóricas. Un Estudio Monte Carlo para Contrarrestar un Nuevo Método. *Grupo de eficiencia y Porductividad Efiuco*.

Pastor, J. (1995, Junio). *Eficiencia, Cambio Productivo y Cambio Técnico en los Bancos y Cajas de Ahorro Españolas: Un Análisis de Frontera No Paramétrico*. Ponencia presentada en el VII congreso de Asociación Científica Europea de Científicos de Economía Aplicada *Instituto Valenciano de Investigaciones Económicas*. Recuperado de http://aeea.webs.upv.es/aeea/ficheros/congresos/congresoAlbacete2007/ACTAS_VI_CEA-AEEA.pdf

Pierri, N. (2005, Julio). *Sustentabilidad? Desacuerdos sobre el Desarrollo Sostenible. Colección América Latina y Nuevo Orden Mundial.* (1ª ed.). D.F., México: Universidad Autónoma de Zacatecas & Miguel Angel Porrúa.

Pistonesi, H., Nadal, G., Bravo, V., & Bouille, D. (2008, Marzo). *Aporte de los Biocombustibes a la Sustentabilidad del Desarrollo en América Latina y el Caribe: Elementos para la Formulación de Políticas Públicas.* Santiago de Chile: CEPAL.

Quiroz, J. (2014). *El Destino Está en los Detalles: Las Leyes Secundarias y la Reforma Energética.* México: Instituto Michoacano Para la Competitividad (IMCO).

R, B., A., C., & Cooper., W. (1984). Some models for estimating technical and scales inefficiencies. *Data Envelopment Analysis*, 30, 1078-1092.

Rojas,R. (2001). *Guía para Realizar Investigaciones Sociales* (27a. Ed.). D.F., México: Plaza y Valdés.

Romeu, A., & Rodríguez, Y. (2008). *Procedimiento para la Evaluación de la Eficiencia Técnica en la Transportación de Caña en las UPBC Cañeras de la Provincia de Villa Clara.* Santa Clara, Cuba: Universidad Central de Santa Clara.

Sanhueza,E. (2003, Noviembre). Fronteras de Eficiencia, Metodologías para la Determinación del Valor Agregado de Distribución. (Tesis de doctorado). Pontífica Universidad Católica de Chile. Recuperado de http://web.ing.puc.cl/power/paperspdf/sanhuezathesis.pdf

SENER. (2007). *Energías Renovables para el desarrollo sustentable en México.* D.F., México: SENER.

SENER. (2007). *Programa de Introducción de Bioenergéticos.* D.F., México: SENER.

SENER. (2013). *Estrategia Nacional de Energía 2013- 2027.* México, D.F.: SENER. Obtenido de http://www.sener.gob.mx/res/PE_y_DT/pub/2013/ENE_2013-2027.pdf

Schuschny (2007, Enero). El método DEA y su aplicación al Estudio del Sector Energético y las Emisiones de CO2 en América Latina. *CEPAL, 46,* 46-53.

Sierra, R. (2007). *Tesis Doctorales y Trabajos de Investigación Científica* (5a. ed.). Madrid, España: Thompson.

Soimakallio, S., & Koponen, K. (2011, Junio 23). How to Ensure Greenhouse gas Emission Reductions by Increasing the Use of Biofuels? Suitability of the European. *Biomass and Bioenergy, 35,* 3504 - 3513, *http://dx.doi.org/10.1016/j.biombioe.2011.04.041.*

Timilsina, G., & Arshish, S. (2010, Julio). Biofuel, Markets, Targets and Impact. *Policy Research* .

Van Dam, J., Faaij C., A. P., Lewandowski, I., & Zeebroeck Van, J. (2011, Febrero 4). Options of Biofuel Trade From Central and Eastern to Western European Countries. *Biomass and Bioenergy*, 33, 728–744, http://dx.doi.org/10.1016/j.biombioe.2008.11.006