Article

Analysis of the efficiency and returns to scale of sugar mills in Mexico

Ramón Valdivia Alcala[1]
Cristóbal Martín Cuevas Alvarado[2§]
Juan Salvador Vázquez Muñoz[1]
Mario Ivan García Hernández[1]
Ilich Miguel Santiago Zarate[1]
Ángeles Suhgey Garay Jácome[1]

[1]Postgraduate Program of the Division of Administrative Economic Sciences-Chapingo Autonomous University. Mexico-Texcoco Highway km 38.5, Chapingo, Texcoco, State of Mexico, Mexico. CP. 56230. Tel. 595 9517058. (ramvaldi@gmail.com; sazami.09@gmail.com; ivan.garcya@gmail.com; anllely0608@gmail.com). [2]Independent Consultant-Researcher. 28 Arboledas Street, Montecillo, Texcoco, State of Mexico. CP. 56264. Tel. 55 61651251.

[§]Corresponding author: cuevas_cristobal@hotmail.com.

Abstract

In Mexico, the sugarcane agroindustry is important in the economy of 25 states and 267 municipalities. In the 1995-1996 harvest, 61 sugar mills operated and in the 2017-2018 harvest only 51 mills. In a 19-year period, 16.4% of the milling infrastructure of the Mexican sugarcane agroindustry closed. Technically, there are inefficiencies in their parameters that influenced their closure. The present research aims to analyze the efficiency and nature of the returns to scale with which sugar mills operated in Mexico in the 2010-2011 harvest. The methodology used was data envelopment analysis (DEA). The results indicate that 23 mills operated at their optimal scale, nine mills with total efficiency, but with pure inefficiency and scale inefficiency, and a third group operated with total inefficiency, pure inefficiency and scale inefficiency. As for the nature of the returns to scale, the DEA identified that 23 mills operated with constant returns to scale, 29 with increasing returns to scale and only two mills with diminishing returns to scale. The main conclusion indicates that the 29 mills with increasing returns to scale can improve their performance if they expand their size, production and factor productivity would increase more than proportionally. The mill Panuco is the only one that was identified with both scale inefficiency and diminishing returns to scale, so such performance could lead it to stop operating and close as a plant.

Keywords: data envelopment analysis, economies of scale, stochastic frontier analysis, total factor productivity.

Reception date: November 2021
Acceptance date: February 2022

Introduction

According to CONADESUCA (2019), sugarcane in Mexico is a relevant crop because the agroindustry of this crop has a presence in 15 states and 267 municipalities and generates a significant number of direct and indirect jobs. According to CEMA (2017) in the 2016-2017 harvest, 184 171 producers participated, of which 71.5% corresponds to *ejidatarios* (shareholders of common land), 24.6% to smallholders and 3.9% to other types of producers such as tenants and school plots. For the same harvest, CONADESUCA (2019) reported 68 365 participating cutters. In this way, under the assumption that the producers employ themselves directly in the harvest and that the cutters can effectively be considered as employees, then one will be talking about 252 536 direct jobs.

In addition, if it is also assumed that for every direct job three direct jobs are generated, then one would be talking about the generation of 1 010 144 jobs generated in the field link of the sugarcane agroindustry. However, in the 2018-2019 harvest, 804 060 ha were industrialized with a sugar production of 6.4 million tons. According to the SIAP (2019), sugarcane represented in the agricultural year 2019, 6.8% of the total value of agricultural production, ranking third, only behind corn and avocado, which represented 17.7% and 7.7%, respectively.

Sugarcane is the only crop in Mexico that has a regulation that regulates the relations between sugarcane mills and sugarcane farmers. This regulation is the Law of Sustainable Development of Sugarcane published in 2005 (SAGARPA, 2005), which together with the National Program for the Cane Agroindustry (SAGARPA, 2014) are the normative instruments and that give guidelines for the planning, modernization and improvement of competitiveness via crop research.

However, although there is such a specific program for agroindustry, in practice, the operability, profitability and the boost to the manufacturing capacity of agroindustry presents challenges emanating from the almost permanent structural crisis of the sugarcane sector. In this sense, there have been two moments in which the situation of the sugar mills has entered in crisis, which has caused the intervention of the public sector. Between the second decade of the twentieth century and the 80s of the same centuries, the sugar mills were managed by the State.

The characteristic of these periods was the application of subsidies and an erratic business policy. The situation worsened between 1988 and 1990 because the large volumes of sugar imports caused an oversupply, mills were overindebted and with an overdue portfolio, had limited access to credit, high production costs and price fixing was punished up to 15% below the agreed price. In addition to the above, there was stagnation in the productivity of sugarcane fields and mills with loss of profitability, which made it difficult to pay debts, so several mills closed definitively.

It is in this context that in 1988 the government made the decision to sell the mills to a group of businessmen, among whom were partners of the soft drink companies, with the argument of the modernization of agroindustry (Molina, 2019).

The second intervention of the public sector in the sugarcane agroindustry took place in 2001. According to Molina (2019), the government decided to nationalize 27 mills with the argument of alleviating the crisis that at that time the mills registered, which dragged fiscal, social security and credit debts and debts with producers and day laborers, which amounted to more than 3 billion dollars. The corollary of such crises has been inefficient productive infrastructure and technology, high production costs and little diversification in the use of co-products and by-products obtained in the sugar mill and distillery.

According to the National Union of Sugarcane Growers, Civil Association, linked to the National Confederation of Rural Owners (UNC-CNPR, 1996), the area of industrialized cane in the 1995-1996 harvest was 577 106 ha with a yield of 69.63 t ha^{-1} and net milled cane production of 39 415 468 t produced in 61 mills. However, in the 1996 harvest 61 sugar mills operated while in the 2015 harvest 51 operated. In this way, in a period of 19 years, 10 mills stopped operating in the sugarcane agroindustry; that is, an average of approximately one mill stopped operating or closed every two years.

The analysis of a series of indicators of the productivity of the sugarcane agroindustry shows that it has had a series of inefficiencies and technological backwardness that have had an impact on its profitability and probably influenced the closure of 22% of the existing mills in a period of 19 years. According to the Fideicomisos Instituidos en Relación a la Agricultura (2016), sugarcane is an input that could generate products such as biofertilizers, biofuels, carbon credits for the reduction of polluting emissions, etc.

This could generate additional incomes and improve the profitability position of the mills. However, agroindustry is poorly diversified and shows inefficiencies in several technical parameters. Among the main ones are: Industrial plants have only taken advantage of 39% of the total caloric content of one ton of cane (1.2 million kilocalories). The sugarcane agroindustry buys approximately 6.3% of electricity from the Federal Electricity Commission (CFE) to be able to mill sugarcane, which raises its operating costs. That is, the sugarcane agroindustry is not self-sufficient in the generation of electricity for self-consumption, even though the existing legal framework allows it to generate surpluses through cogeneration and sell it to the CFE, which could constitute a source of income that improves its financial balance sheets.

The average lost time per harvest in the period 2005 to 2016 of the total harvest hours per year (209 818 hours) is 19.1%. This 19.1% is distributed as follows: 3.3% in the field, 8.9% in the factory, 0.4% due to holidays, 5.4% due to rains and 1.1% due to aspects attributable to personnel. Most of the total lost time corresponds to mill itself due to the insufficient plant maintenance and replacement of problematic or obsolete equipment. In the period 2005 to 2016, the sugarcane agroindustry has paid on average 118.28 kg of sugar per ton of net milled cane to producers; however, the kilos of sugar actually obtained on average per ton of net milled cane were 117.38 kg.

The mill is not reaching the efficiency indicated in the Law of Sustainable Development of Sugarcane for the payment of cane based on the reference price determined by CONADESUCA, so the mill is paying an extra cost of 0.765 kg t^{-1} of sugarcane that in monetary terms has meant an additional expenditure of 3 044 740 million pesos.

A parameter that shows the technological backwardness of the physical equipment of the mills is reflected in the so-called specific consumption of steam of sugarcane; a totally inefficient use of cane bagasse and oil, due to the use of boilers and turbogenerators that operate at very low pressures and low steam temperatures.

As mentioned, in the period 1995-1996, 61 sugar mills operated while in the 2015-2016 harvest only 51 did, in a period of 19 years 10 mills closed, which represents 19.6% of these units, so it is of interest the analysis of the 51 sugar mills that operated in the 2015-2016 harvest.

The data envelopment analysis methodology has been used to measure the efficiency in the use of resources in various economic activities. Becerril *et al*. (2011) applied it to measure the technical efficiency of the Mexican agricultural sector. Fontalvo and De la Hoz (2016) used it to measure the efficiency of hospitals in a Colombian city; Quintanilha *et al*. (2012) used this methodology to measure the efficiency of Brazilian airlines, it has also been used to measure efficiency in credit unions (Belmonte and Plaza, 2008) and in the measurement of crops such as coffee in Colombia (Perdomo and Mendieta, 2007). Jaforullah and Whiteman (1999) used the data envelopment analysis methodology to measure the scale efficiency of New Zealand’s dairy industry and examine the relationship between farm size and technical efficiency.

Tetteh *et al*. (2016) assess the technical efficiency and scale efficiency of small-scale rice farmers in northern Ghana as well as the effect of farm size on efficiency, using data envelopment analysis to measure efficiency. In this context, the present study aims to evaluate the efficiency performance of Mexico’s sugar mills for the 2010-2011 harvest by estimating the scale efficiency and nature of the returns to scale at which they operated in that harvest and to determine which mills could stop operating given their inefficiencies.

Materials and methods

For the determination of the efficiency and nature of the returns to scale, the data envelopment analysis was used in the research. The concept of technical efficiency, in the context of envelopment data analysis, was initiated by Charnes *et al*. (1978), whose challenge was originally to estimate such a concept of technical efficiency considering multiple inputs, multiple products and without the usual price information. The result of that work was the formulation of the Charnes-Cooper-Rhodes (CCR) model of the DEA in the form of a quotient or fractional programming.

In contrast to parametric approaches, which aim to optimize a single plane of regression through the data, the DEA optimizes a ‘model’ for each individual observation with the aim of calculating a discrete piecewise frontier determined by the set of Pareto-efficient decision-making units (DMUs). Both approaches, the parametric and the non-parametric use all the information contained in the data. In parametric analysis, the optimized regression line is assumed to apply to each of DMU.

DEA analysis optimizes the measure, in contrast, of the performance of each DMU. This results in a revealed understanding about each DMU rather than the typical average DMU. In other words, the DEA's focus is on individual observations; that is, observation by observation, in contrast to the approach of averages and estimation of parameters that are associated with the statistical approaches of a single optimization (Charnes *et al*., 1994).

The CCR assumes, as mentioned, constant returns to scale (CRS). This model is appropriate when all the firms analyzed operate on the optimal scale. Charnes *et al*. (1978) define efficiency as the maximum of a quotient of weighted output between weighted inputs subject to the fact that similar quotients for each DMU are less than or equal to the unit. According to Huguenin (2012), in mathematical form these ideas can be expressed as follows: $TE_K=\frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}}$. Where: TE_k is the relative technical efficiency of the firm k that uses k inputs to produce s products and also; y_{rk}= quantity of product r produced by firm k; x_{ik}= amount of input i consumed by firm k; u_r= weight of product r; v_i= weight of input i; s= number of products; and m= number of inputs.

The technical efficiency of company k is maximized under two constraints. First, the weights applied to the outputs and inputs of firm k cannot generate an efficiency score greater than 1 when applied to each company in the dataset. Second, the weights of outputs and inputs are strictly positive. In this way, for each firm, the following linear programming problem must be solved: $maximizar\ \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}}$ subject to $\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1$ j= 1,..., n j= 1,..., n u_r, v_i> 0 ∀r= 1,..., s; i= 1,..., m.

The notation of this fraction al programming problem is the same as described in the last two paragraphs. This linear programming problem can be dealt with by following two different approaches. In the first case, the weighted sums of inputs are minimized holding outputs constant (product-oriented model). In the second case, the weighted sums of inputs are maximized holding inputs constant (oriented-input model).

As is known, the solution can be obtained by processing the primal or the dual of the linear programming problem. The primal equations for each model, expressed in its multiplicative form, are as follows and also the notation is the one described for the expression of the relative technical efficiency of the unit k (TE_k).

Product-oriented CRS model

Min $\sum_{i=1}^{m} v_i x_{ik}$ Sujeto a $\sum_{i}^{m} v_i x_{ij}$- $\sum_{r=1}^{s} u_r y_{rj} \geq 0$ j= 1,..., n $\sum_{r=1}^{s} u_r y_{rk} = 1$ $u_r, v_i > 0$ ∀r= 1,..s; i= 1,..., m

Input-oriented CRS model

Max $\sum_{r=1}^{s} u_r y_{rk}$ Sujeto a $\sum_{i=1}^{m} v_i x_{ij}$- $\sum_{r=1}^{s} u_r y_{rj} \geq 0$ j= 1,.., n $\sum_{i=1}^{m} v_i x_{ik} = 1$ $u_r, v_i > 0$ ∀r= 1,..., s; i= 1,..., m

The materials from which the information was obtained to feed the mathematical programming models, on which the data envelopment analysis method is based, was the 'statistical report of the agro-industrial sector of sugarcane in Mexico harvests 2006-2007-2015-2016' (CONADESUCA, 2017). This document contains abundant official information on sugarcane both in the field and in the factory.

The official information was contrasted with the information published by the UNC-CNPR (2017), which is one of the two organizations that supply raw material for sugar mills and represents the smallholders who grow sugarcane. The selected period, the 2010-2011 harvest, is because the information of all the mills is complete and does not contain lost data. It should be noted that cross-sectional data were used in this study; that is, for a single period considering all decision-making units (DMUs) or sugar mills.

The software used to run the models of data envelopment analysis was the Data Envelopment Analysis Program 2.1 (DEAP 2.1) of Coelli (1996). Tetteh *et al*. (2016) point out that the DEA approach generates a data envelopment surface by linking the points in the input-output space in such a way that it no longer allows the production of more product using the same input level or the production of the same product using fewer inputs. The data envelopment surface serves as a reference point for measuring the relative efficiency of the rest of the companies below the envelope surface.

Empirically this means that all efficient units are linked by a continuum to form an efficient frontier in which the efficiency score for each decision-making unit is measured by how far it deviates from the efficient frontier.

The frontier for constant returns to scale is linear, while for variable returns to scale it is a convex piecewise envelope. It is possible to break down the efficiency analysis into three dimensions to understand the possible sources of inefficiency. The first dimension relates to overall technical efficiency, the second relates to pure technical efficiency, while the third relates to scale efficiency.

Estimating overall technical efficiency involves measuring the ratio between the distance between inefficient points and the efficient frontier of constant returns to scale (CRS), while estimating pure technical efficiency involves measuring the ratio between the distance between inefficient points and the efficient frontier under variable returns to scale (VRS). Scale efficiency (SE) is the ratio between overall technical efficiency (OTE) and pure technical efficiency (PTE). The study by Tetteh *et al*. (2016) uses input orientation in estimation because producers have more control over inputs than over production.

Results and discussion

According to CONADESUCA (2018), in the 2015-2016 harvest, the sugarcane agroindustry in Mexico operated with 51 sugarcane mills. Of these, there are 18 in Veracruz (35.3%), 6 in Jalisco (11.8%), 4 in San Luis Potosí (7.8%), 3 in Michoacán (5.9%) and 3 in Oaxaca (5.9%). These five states account for 66.7% of the sugarcane agroindustry in Mexico.

The variables used to construct the DEA model based on linear programming, calculate the technical efficiency of decision-making units under constant returns to scale, variable returns to scale and scale efficiency are shown in Table 1, while descriptive statistics of such variables are shown in Table 2. The units of the variables are those shown in the second column of Table 1.

Table 1. Definition of the variables used.

Variable	Units	Type
Sugar produced per hectare	Tonnes	Output
Filter cake	Tonnes	Output
Total energy consumed	Kw-h	Input
Haulage vehicles	Units	Input
Net milled cane	Tonnes	Input
Cutters	Day laborers	Input
Cutting fronts	Units	Input
Harvest time lost	Hours	Input

CONADESUCA (2017).

Table 2 Descriptive statistics of the variables used, 2010-2011 harvest.

Variable	Average	Maximum value	Minimum value	Coefficient of variation (%)
Sugar produced per hectare	97 465	228 998	10 482	57.5
Filter cake	112 029	290 372	15 458	68.6
Total energy consumed	496 066 300	1 181 558 548	87 691 047	54.3
Haulage vehicles	298	1 393	31	75.2
Net milled cane	12 628	35 865	1 523	58.3
Cutters	796 046	1 760 707	122 682	54.1
Cutting fronts	1 320	3 839	76	64.4
Harvest time lost	3 427	5 616	1 087	25.3
Sugar produced per hectare	517	1 361	67	52

CONADESUCA (2017).

Once an exploratory analysis of the data was performed and analyzing the descriptive statistics to detect observations that could distort the analysis, the DEA model was processed for the calculation of technical efficiency under the assumption of constant returns to scale and the DEA model under the assumption of variable returns to scale. As mentioned above, scale efficiency is obtained as the quotient of technical efficiency (under the assumption of constant returns to scale) and technical efficiency (under the assumption of variable returns to scale). Before proceeding with the analysis, it is necessary to mention that the efficiency obtained under constant returns to scale is called total efficiency, the efficiency obtained under variable returns to scale is called pure efficiency (Coelli *et al*., 1998; Coelli and Prasada *et al*., 2005; Zhu, 2013).

Mills operating at optimal scale

In the group of sugar mills that operated at their optimal scale, that is, those whose efficiency indices under constant returns to scale (total efficiency), variable returns to scale (pure efficiency) and scale efficiency are equal to the unit, were 23 mills: Adolfo López Mateos, Alianza Popular, Atencingo, Central Casasano, Central Motzorongo, El Higo, El Molino, El Potrero, El Dorado, Emiliano Zapata, La Gloria, Los Mochis, Melchor Ocampo, Nuevo San Francisco, La Margarita, Plan de San Luis, Puga, Pujiltic, San Cristóbal, San Miguel del Naranjo, Tala, Tamazula and Tres Valles. The fact that a mill operates at its optimal scale means that the inputs used in the production process, such as land, haulage units, cutters, harvest hours, energy used to generate milling power, etc., are being used and managed with the best productive practices. The optimal scale implies that sugar mills are working at their optimal size.

Mills operating with total inefficiency and scale inefficiency

In the second group of mills are those decision-making units that operated with total efficiency and scale efficiency lower than the unit. This group has 8 sugar mills as shown in Table 3.

Table 3. Sugar mills operating with total and scale inefficiency 2010-2011.

	Mill		Efficiency	
1	Azsuremex	0.6482	1	0.6482
2	Calipam	0.8178	1	0.8178
3	Santa Clara	0.8384	1	0.8384
4	Bellavista	0.8531	1	0.8531
5	Pedernales	0.9129	1	0.9129
6	Lázaro Cárdenas	0.9336	1	0.9336
7	José María Morelos	0.9383	1	0.9383
8	San Francisco Ameca	0.9523	1	0.9523

In this second group of mills, the efficiency indicators show the following: pure efficiency indicates that the resources and inputs used are used and managed with the best productive practices. The source of inefficiency of these mills is their size. Therefore, if such mills expanded their scale, they would improve their efficiency and productivity. In this case, the mill Azsuremex stands out, whose total efficiency and scale efficiency is low (64.82%), so expanding its scale of operation would improve its efficiency to almost 35%.

Mills operating with total inefficiency, pure inefficiency and scale inefficiency

In a third group of mills are those decision-making units whose inefficiencies come both from a mismanagement of the resources and inputs that participate in the field link and from the milling process in the factory link, as well as from the scale inefficiency; that is, because of the size of the mill. In this group were 22 mills, as shown in Table 4.

In this group of mills, the case of Santa Rosalía stands out. The greater inefficiency of this mill is explained, in the study harvest, by the mismanagement and administration of productive resources and mill, its pure inefficiency was 16% while its scale inefficiency was 6%. The total inefficiency of this mill was 21.32%. In that harvest, the mills Presidente Benito Juárez, Cuatotolapam, among others, had a very similar situation.

Table 4. Sugar mills with pure and scale inefficiency 2010-2011.

	Mill	Efficiency		
1	El Carmen	0.8185	0.9062	0.9032
2	San Miguelito	0.8836	0.9684	0.9124
3	San Pedro	0.8436	0.9152	0.9218
4	Cuatotolapam	0.8211	0.8792	0.9339
5	Santa Rosalía	0.7868	0.8367	0.9404
6	El Refugio	0.9409	0.9989	0.9419
7	San José de Abajo	0.8849	0.9379	0.9434
8	Mahuixtlán	0.9033	0.9558	0.9451
9	Huixtla	0.8319	0.8799	0.9455
10	El Modelo	0.8971	0.9401	0.9543
11	La Joya	0.8975	0.9386	0.9562
12	Presidente Benito Juárez	0.8246	0.8486	0.9717
13	Central La Providencia	0.917	0.9433	0.9721
14	San Rafael de Pucté	0.9005	0.9117	0.9877
15	Constancia	0.9082	0.9194	0.9878
16	Central Progreso	0.9350	0.9449	0.9895
17	El Mante	0.9328	0.9412	0.9911
18	San Nicolás	0.8943	0.9008	0.9929
19	Plan de Ayala	0.9735	0.9784	0.995
20	Aarón Sáenz Garza	0.9667	0.969	0.9976
21	Quesería	0.9208	0.9216	0.9991
22	Pánuco	0.9675	0.968	0.9995

Identifying returns to scale

In identifying the nature of the returns to scale that each plant of the national sugar agroindustry has, the so-called non-increasing returns to scale (NIRS) play a relevant role. This concept is itself the subject of complete studies. However, since the software calculates it automatically, it is common for it to be used in conjunction with pure efficiency (or under variable returns to scale) and total efficiency (or under constant returns to scale) to identify what kind of returns to scale Mexican mills have, in this case. From three rules, it is possible to identify the nature of returns to scale.

When pure efficiency equals efficiency under NIRS, the mill operates under diminishing returns to scale. When pure efficiency equals total efficiency, and these are equal to efficiency under NIRS, the mill is operating under constant returns to scale. When total efficiency equals efficiency under NIRS, the mill is operating under increasing returns to scale. In the first case, there was only one sugar mill and corresponded to the mill Pánuco and is shown in Table 5.

Table 5. Sugarcane mills with diminishing returns to scale 2010-2011.

No.	Mills	Efficiency			Nature of returns to scale
		Under CRS	Under VRS	Under NIRS	
		(total)	(pure)		
1	Pánuco	0.9675	0.968	0.968	Diminishing

The case of the mill Pánuco is the most critical, since the diminishing returns to scale are characterized because if its scale (size) is increased, production will increase in a smaller proportion and the productivity of the factors will decrease. Although this result was for the 2010-2011 harvest, it would be expected that, if it had had a similar behavior in later harvests, it could stop operating. The second case corresponds to the group of 23 mills that operated at the optimal scale; that is, the total efficiency, the pure efficiency and therefore the scale efficiency are equal to the unit. These mills operated with constant returns to scale and those mentioned in the first group of the previous section.

In the third case are those mills that operated under increasing returns to scale. In this group, 29 mills were identified and are shown in Table 6. According to economic theory, mills with increasing returns to scale can improve their efficiency, because if they increased their installed capacity, production would increase by a greater proportion and factor productivity would increase.

Table 6. Sugarcane mills with increasing returns to scale 2010-2011.

No.	Mill	Efficiency			Nature of returns to scale
		Under CRS	Under VRS	Under NIRS	
		(Total)	(Pure)		
1	Azsuremex	0.6482	1	0.6482	Increasing
2	Santa Rosalía	0.7868	0.8367	0.7868	Increasing
3	Calipam	0.8178	1	0.8178	Increasing
4	El Carmen	0.8185	0.9062	0.8185	Increasing
5	Cuatotolapam	0.8211	0.8792	0.8211	Increasing
6	Presidente Benito Juárez	0.8246	0.8486	0.8246	Increasing
7	Huixtla	0.8319	0.8799	0.8319	Increasing
8	Santa Clara	0.8384	1	0.8384	Increasing
9	San Pedro	0.8436	0.9152	0.8436	Increasing
10	Bellavista	0.8531	1	0.8531	Increasing
11	San Miguelito	0.8836	0.9684	0.8836	Increasing
12	San José de Abajo	0.8849	0.9379	0.8849	Increasing
13	San Nicolás	0.8943	0.9008	0.8943	Increasing
14	El Modelo	0.8971	0.9401	0.8971	Increasing
15	La Joya	0.8975	0.9386	0.8975	Increasing

No.	Mill	Efficiency			Nature of returns to scale
		Under CRS	Under VRS	Under NIRS	
		(Total)	(Pure)		
16	San Rafael de Pucté	0.9005	0.9117	0.9005	Increasing
17	Mahuixtlán	0.9033	0.9558	0.9033	Increasing
18	Constancia	0.9082	0.9194	0.9082	Increasing
19	Pedernales	0.9129	1	0.9129	Increasing
20	Central La Providencia	0.917	0.9433	0.917	Increasing
21	Quesería	0.9208	0.9216	0.9208	Increasing
22	El Mante	0.9328	0.9412	0.9328	Increasing
23	Lázaro Cárdenas	0.9336	1	0.9336	Increasing
24	Central Progreso	0.935	0.9449	0.935	Increasing
25	José María Morelos	0.9383	1	0.9383	Increasing
26	El Refugio	0.9409	0.9989	0.9409	Increasing
27	San Francisco Ameca	0.9523	1	0.9523	Increasing
28	Aarón Sáenz Garza	0.9667	0.969	0.9667	Increasing
29	Plan de Ayala	0.9735	0.9784	0.9735	Increasing

When comparing these results with those of other investigations, two situations were found. Campos and Oviedo (2015); Pérez (2007); Sen (1962), although they study the size of the farms on the productivity of sugarcane per hectare, they only do so through descriptive statistics, mainly the mean, which causes their quantitative results not to be comparable with those obtained with the data envelopment analysis (DEA) methodology.

Other results, although derived from the DEA methodology for studying scale efficiency and the nature of returns to scale, do so for products other than sugarcane. So, the discussion is reduced only to contrast the results obtained with studies that analyze other agroindustries or sector of the economy. In this way it can be affirmed that the present research is a pioneer, in Mexico, in determining the scale efficiency and returns to scale using the DEA methodology. Thus, for example, Jaforullab and Whiteman (1999) empirically broke down total efficiency into pure and scale efficiency in New Zealand's dairy agroindustry. The results showed that 19% of farms are operating at their optimal scale, 28% are above their optimal scale and 57% were below their optimal scale. A relevant result is also that the size of dairy farms over time increase in size, but their number decreases.

Conclusions

It was found that 23 mills operated at their optimal scale and presented constant returns to scale, which implies that the management of the resources they have is efficient. A second group of mills that presented increasing returns to scale was found, which implies that they can improve their efficiency because if they increase the use of inputs in a certain proportion, the product obtained will increase more than proportionally. In this group were 29 sugar mills. Finally, a third group that presented diminishing returns to scale; that is, if resources, such as harvested area, machinery, among others, increase, their cane production will decrease. In this case is the mill Pánuco. The overall conclusion of the study is that the presence of a higher number of mills with increasing returns to scale (29) implies that there is an opportunity to improve the efficiency of the national sugarcane agroindustry. This study is the first to determine the scale efficiency and nature of returns to scale using the efficient frontier methodology in the sugarcane agroindustry in Mexico.

Cited literature

Becerril, T. O. U.; Rodríguez, L. G y Ramírez, H. J. J. 2011. Eficiencia técnica del sector agropecuario de México: una perspectiva de análisis envolvente de datos. Economía. 34(31):85-110. https://www.redalyc.org/articulo.oa?id=195621325004.

Belmonte, U. L. J. y Plaza, Ú. J. A. 2008. Análisis de la eficiencia en las cooperativas de crédito en España. Una propuesta metodológica basada en el análisis envolvente de datos (DEA). Rev. Econ. Púb. Soc. Coop. 22(63):113-133. https://ojs.uv.es/index.php/ciriecespana/index.

CEMA. 2017. Compañía Editora del Manual Azucarero Mexicano. Manual azucarero mexicano. (Ed.) Cía. Editora del Manual Azucarero, SA de CV Ciudad de México, México. 487 p.

Campos, O. F. y Oviedo, P. M. 2015. Extensión de los predios agrícolas y productividad. El caso del campo cañero en México. El Trimestre Económico. 80(325):147-181.

Charnes, A.; Cooper, W. W.; Lewin, A. Y. and Seiford, L. M. 1994. Data envelopment analysis. Theory, methodology, and application. Springer Science+Business Media LLC. New York, NY. 507 p.

Charnes, A.; Cooper, W. W. and Rhodes, E. 1978. Measuring the efficiency of decision-making units. Eur. J. Oper. Res. 2(6):429-444. Doi:https://doi.org/10.1016/0377-2217(78)90138-8.

Coelli, T. 1996. A guide to DEAP. Version 2.1: a data envelopment analysis (computer) program. Centre for Efficiency and Productivity Analysis. University of New England, Australia. http://www.owlnet.rice.edu/~econ380/DEAP.PDF.

Coelli, T. J.; Prasada, R, D. S. P.; O'Donnell, C. J. and Battese, G. E. 2005. An introduction to efficiency and productivity analysis. 2th (Ed.). Springer: New York, NY, USA. 341 p.

Coelli, T. J.; Prasada, R. D. S. and Battese, G. E. 1998. An Introduction to efficiency and productivity analysis. Kluwer Academic Publisher. Boston, Massachusetts, USA. 341 p.

CONADESUCA. 2017. Comité Nacional para el Desarrollo sustentable de la caña de azúcar. Informe estadístico del sector agroindustrial de la caña de azúcar en México Zafras 2006-2007/2015-2016. Ciudad de México, México. https://www.gob.mx/conadesuca/articulos/informe-estadistico-del-sector-agroindustrial-de-la-cana-de-azucar-en-mexico-zafras-2006-2007-2015-2016?idiom=es.

CONADESUCA. 2018. Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar. Quinto informe estadístico del sector agroindustrial de la caña de azúcar en México Zafras 2008-2009/2017-2018. Ciudad de México, México. https://www.gob.mx/cms/uploads/attachment/file/392732/Nacional_y_Entidad_Federativa.pdf.

CONADESUCA. 2019. Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar. 6° Informe estadístico del sector agroindustrial de la caña de azúcar en México. Zafras 2009-2010/2018-2019. Ciudad de México, México. https://www.gob.mx/conadesuca/es/articulos/6-informe-estadistico-del-sector-agroindustrial-de-la-cana-de-azucar-en-mexico?idiom=es. Zafras 2009-2010 / 2018-2019.

FIRA. 2016. Fideicomisos Instituidos en Relación a la Agricultura. Panorama agroalimentario. Azúcar 2015. Morelia, Michoacán, México. https://www.gob.mx/cms/uploads/attachment/file/61947/Panorama_Agroalimentario_Az_car_2015.pdf.

Fontalvo, H. T. J. y De la Hoz, H. G. 2016. Eficiencia de los hospitales de Bolívar, Colombia, por medio análisis envolvente de datos. Dimensión Empresarial. 14(1):95-108.

Huguenin, J. M. 2012. Data envelopment analysis (DEA). A pedagogical guide for decision makers in the public sector. Institut de Hautes Études en Administration Publique (IHEAP). Laussane, Swiis. https://serval.unil.ch/en/notice/serval:BIB_0FC432348A97.

Jaforullah, M. and Whiteman, J. 1999. Scale efficiency in the New Zealand dairy industry: a non-parametric approach. The Australian J. Agric. Res. Econ. 43(4):523-541. Doi:10.1111/1467-8489.00093.

Molina, E. I. 2019. Iniciativa que reforma diversas disposiciones de la ley de desarrollo sustentable de la caña de azúcar. Sistema de Información Legislativa. Secretaría de Gobernación. http://si1.gobernacion.gob.mx/portal.

Perdomo, J. A. y Mendieta, J. C. 2007. Factores que afectan la eficiencia técnica y asignativa en el sector cafetero colombiano: una aplicación con análisis envolvente de datos. Desarrollo y Sociedad. 2(60):1-46.

Pérez, Z. A. 2007. Tenencia de la tierra e industria azucarera. (Ed.) Porrúa. México, DF. 226 p.

Quintanilha, da S. J.; Baptista, J. C. C. y Angulo, M. L. 2012. Evaluación de la eficiencia de las compañías aéreas brasileñas a través de un modelo híbrido de análisis envolvente de datos (DEA) y programación lineal multiobjetivo. Ingeniare. Rev. Chilena de Ingeniería. 20(3):331-342.

SAGARPA. 2005. Secretaría de Agricultura, Ganadería, Desarrollo Rural Pesca y alimentación. Ley de desarrollo sustentable de la caña de azúcar. Diario Oficial de la Federación (DOF) del 22 de agosto de 2005. DF, México.

SAGARPA-CONADESUCA. 2014. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación-Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar. Programa Nacional de la Agroindustria de la Caña de Azúcar (PRONAC). Diario Oficial de la Federación (DOF) del 2 de mayo de 2014. DF, México.

Sen, A. K. 1962. An aspect of Indian agriculture. Economic & Political Weekly. 14(4-6):243-245.

SIAP. 2019. Servicio de Información Agroindustrial y Pesquera. Anuario estadístico de la producción agrícola. Producción agrícola. Año 2019. Ciudad de México, México. https://nube.siap.gob.mx/cierreagricola/.

Tetteh, A. B.; Backman, S. and Rezitis, A. 2016. Does farm size matter? Investigating scale efficiency of peasant rice farmers in northern Ghana. Economics Bulletin. 36(4):2275-2290.

UNC-CNPR. 2017. Unión Nacional de Cañeros-Confederación Nacional de Propietarios Rurales. Estadisticas de la Agroindustria de Caña de Azúcar. 2005-2006/2015-2016. DF, Méxo.

Zhu, J. 2013. Quantitative models for performance evaluation and benchmarking. Data envelopment analysis with spreadsheets. Springer. New York. 420 p.