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Article

Technical efficiency and economies of scale of sugar mills in Mexico

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Abstract

During the last decade the sugarcane agroindustry has shown great dynamism by constantly increasing the production of standard sugar and guaranteeing the self-sufficiency of this sweetener in the country, even generating surpluses for export. Nevertheless, even in official documents, it is pointed out that this agroindustry presents a marked technological backwardness and inefficiency. The study was conducted in 2021. This work has two objectives: to estimate the overall technical efficiency by mill and break it down into pure efficiency and scale efficiency, as well as to determine the type of returns to scale of each sugar mill. The method used was the data envelopment analysis and elasticity of scale. The study period was the 2009-2010 harvest, and 54 mills were considered, for which disaggregated information was available. The main finding showed that only 21 mills (38.9%) had an optimal performance as they operated with constant returns to scale. Another 28 mills (51.9%) operated with increasing returns to scale and only five mills (9.3%) operated with decreasing returns to scale. These findings were confirmed by the magnitudes of the elasticity of scale of each group of mills. The main conclusion is that more than ten years ago there was room for mills that operated with increasing returns to scale to be restructured in size and management of inputs over which they have control, which would have allowed improving their overall performance by obtaining economies of scale and improve their pure efficiency and therefore, for the sugarcane agribusiness as a whole.

Keywords:

diseconomies of scale, input orientation, returns to scale, sugarcane agroindustry.

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Introduction

In Mexico, sugarcane cultivation is important, as shown by several indicators. In the 2019 agricultural year, with only 4% of the national harvested area, sugarcane participated with 6.8% of the gross value of national agricultural production, for grain corn, which represented 34.6% of the national harvested area and contributed 15.5% of the value of production; and for avocado, which with 1.1% of the area participated with 7.3% of the gross value of national agricultural production (SIAP, 2020). According to CEMA (2017) , 184 171 producers participated in the 2016-2017 harvest, 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.

In that same harvest, 69 971 cutters were used (CONADESUCA, 2017). The sugarcane agroindustry is important not only because of the indicators listed above, but also because the cultivation is carried out in 15 states and impacts 267 municipalities (CONADESUCA, 2020b). According to CONADESUCA (2020b) , in the 2019-2020 harvest, this national agroindustry, with its installed capacity in 50 mills that operated, industrialized 783 thousand h, milled 49 million tonnes of raw cane and obtained a production of 5.3 million tonnes of sugar, which guarantees the self-sufficiency of the national market of this sweetener and compliance with international trade commitments, such as those contracted with the States United States of America.

In the legal field, relationships between sugarcane industrialists and suppliers of raw materials in the area of influence of sugar mills are regulated by the Law for the Sustainable Development of Sugarcane (LDSCA, for its acronym in Spanish) of 2005, which establishes specific guidelines regarding activities related to contract agriculture, the processes of sowing, cultivation, harvesting, industrialization and marketing of sugarcane, its products, byproducts, co-products and derivatives. In the above context, the indicators mentioned show that sugarcane is important in Mexican agriculture for its contribution to the economy, employment and as a producer of bulk sugar which is the primary input for other production chains such as the bakery, biscuit industries, among others.

According to FIRA (2016) , the sugarcane agroindustry generally shows a great technological backwardness. Perhaps the most revealing indicator of the critical situation supposedly faced by sugar mills is the fact that, in 24 years, 11 mills have closed or stopped operating, going from 61 that operated in the 1995-1996 harvest to 50 that operated in the 2019-2020 harvest. That is, in that period, 18% of the milling capacity of the sugarcane agroindustry in Mexico has ceased to operate.

However, the study of the performance of an economic unit, whether in agriculture, industry or in the service sector, is carried out through the indices of efficiency and productivity, the most common being those that define productivity in terms of the ratio of units of output per unit of input (Bröchner, 2017).

Although the above measures of productivity provide valuable information on profitability, the technologies used, the management of inputs to produce a unit of output and there are many more indicators about the position of the company or economic unit in the market, its competition, its market share, among others, these are partial indicators that do not allow measuring the efficiency and productivity of the company as a decision-making unit and comparing it against all other units that produce or manufacture the same product or products with similar and homogeneous characteristics, with virtually the same class of inputs (Hackman, 2008 ; Rasmussen, 2011).

In this context, the present research has two objectives. The first is to estimate the overall technical efficiency by mill and disaggregate it into the so-called pure technical efficiency and scale efficiency. The second objective is to determine the type of return to scale of each sugar mill with the help of the types of efficiency and elasticity of scale that each mill presents. The study period is the 2009-2010 harvest, selected because three sugar mills that have currently stopped their milling activities or have closed completely were operating in that harvest, a situation that all allows visualizing if their efficiency indicators were indicative that such a situation could occur.

Materials and methods

In the empirical study of productivity, efficiency and technological change, in the so-called decision-making units (DMUs), two approaches are fundamentally used. The first is the so-called stochastic frontier analysis and the second is the data envelopment analysis. The stochastic frontier method assumes a functional form to which the data fit; hence it is called parametric estimation of efficiency. This method began with the works by Aigner *et al* . (1977); Meeusen and Van den Broeck (1977).

In the case of the data envelopment analysis (DEA), the so-called efficient production frontier is constructed from linear programming, so a particular functional form is not assumed, which is why this method is called nonparametric estimation of efficiency. This way of determining which DMUs are efficient and which are not has been developed from studies by Charnes *et al* . (1978); Banker *et al* . (1984). Both types of efficiency estimation construct efficient frontiers based on DMUs with the best practices, technical and economic, which delimit data from above or below and these frontiers provide empirical approximations to theoretical optima that reflect the so-called technical or economic efficiency.

The two methods of estimating efficiency, or inefficiency as the case may be, originate from the work by Farrell (1957). As mentioned, the work by Charnes *et al* . (1978) was the first to propose the methodology of data envelopment analysis to empirically estimate the efficiency of DMUs. The model of these authors has been called CCR model of constant returns to scale. The first task of the developers of the CCR model was to estimate the technical efficiency in the presence of multiple inputs, multiple outputs and without considering price data.

According to Escobedo *et al* . (2019); Santiago *et al* . (2021); Valdivia *et al* . (2022), the result of the work by Charnes *et al* . (1978) was the formulation of the CCR model of the data envelopment analysis in the form of a quotient or fractional programming. In contrast to the stochastic frontier approach, whose purpose is to optimize a single regression plane through the data, in the nonparametric approach of the DEA, a model is optimized for each observation for the purpose of ‘constructing’ a discrete piecewise frontier determined by the group of Pareto-efficient DMUs.

In the stochastic frontier approach, the optimized regression line is assumed to apply to each of the DMUs, but in the DEA approach, the measurement of the performance of each DMU is optimized, resulting in a revealed understanding about each DMU, rather than the typical average DMU of the regression in the stochastic frontier. In other words, the DEA’s focus is on individual observations; that is, observation by observation, in contrast to the approach of averages and parameter estimation that are associated with statistical approaches of a single optimization (Charnes *et al* ., 1994).

In order to propose the CCR model, it can be assumed that there are N inputs and M outputs for j companies and that for the i-th firm, $x_j$represents a column vector of inputs and q_ja column vector for the output. In addition, it is necessary to assume that X is an Nx1 matrix of inputs and Q an Mx1 matrix of outputs, which represents the production data for all j firms. In addition, (= is a vector of weights of outputs and (the vector of the weighting factors or weights of inputs.

DEA solves the mathematical programming challenge by finding the values of (and (that maximize the efficiency scores of the i-th firm subject to the restriction that efficiency scores must be less than or equal to one:

$$\text{Maximize}(,v)\,\frac{{}^{T}q_i}{v^{T}x_j}$$

$$\text{Subject to}\,\frac{{}^{T}q_j}{{}^{T}x_j}\,1$$

$$\text{with } j= 1,\ldots, n.\ ,\ 0$$

Where: T= represents the transposed matrix operator.

The DEA model established by Charnes *et al* . (1978) was input-oriented and assumed constant returns to scale, while Banker *et al* . (1984) proposed the DEA model with variable returns to scale. The model of constant returns to scale has been called the CCR model in reference to the surnames of its discoverers (Charnes-Cooper-Rhodes), while the DEA model with variable returns to scale has been called the BCC model, also in reference to those who developed it (Banker-Charnes-Cooper).

The CRS model assigns weights to all its inputs and all its outputs and then it is possible to calculate the level of efficiency of each DMU by obtaining the proportion of the weighted aggregate output with the total weighted inputs. To obtain the total technical efficiency, the following procedure is followed. The fractional programming problem has a multitude of solutions, but by introducing a constraint of the form$^{T}q_{i}= 1$, the maximization problem is transformed to the following minimization problem:

$\text{Minimizar}(,)^{T}x_{i}$

$S.\,t.^{T}q_{i}= 1$

$, 0$

$^{T}q_{j}-^{T}x_{j} \leq 0 \; j=1,\ldots, n$

For the calculation of the overall efficiency, this problem must in turn be restated as a maximization problem as follows:

$\text{Maximizar}(_{i},)_{i}$

$S.\,t._{i} \;\; q_{i} \leq {}^{T}Q$

$X_{i} \;\; {}^{T}X$

0

Where: (= is a column vector nx1, while ($_{i}$= is a scalar. The solution to the latter equation yields the overall technical efficiency under the assumption of constant returns to scale (TE_{CRS}) If

$^{*}_{i}1$, the respective DMU is efficient, otherwise it is inefficient.

The BCC model or variable returns to scale model is estimated by using the following linear programming model, in which the condition that the efficient production frontier must satisfy the convexity condition is introduced.

$\text{Maximizar}(_{i}\,)_{i}$

$S.\,t._{i}q_{i} \leq {}^{T}Q+ e^{T}$

$X \geq {}^{T}X$

≥ 0

Where: e= is a column vector of ones. The solution to the latter linear programming model (0_{i}^{**}) is called pure technical efficiency, which is usually denoted as TE_{VRS}.

The so-called scale efficiency (SE) or due to the size with which the DMUs operate, in this case the sugar mills, is calculated by dividing the overall technical efficiency (TE_{CRS}) by the pure technical efficiency. According to Zhu (2003), each DMU can decide whether to operate on a suboptimal scale, that is, with decreasing returns to scale or increasing returns to scale.

In this study, two criteria will be applied to determine the type of returns to scale of sugar mills in Mexico. The first is the one proposed by Zhu (2003), for which, if it is considered that e= is a column vector (nx1) of ones and (*= is a vector (nx1) consisting of the optimal values of the variable (of all the sugar mills of the sugarcane agroindustry, then, according to Zhu (2003),

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if $e^{T}\lambda^{*}=1$, then there are constant returns to scale (CRS) $e^{T*}\langle 1,$ $e^{T}\lambda^{*}\rangle 1$
then there areincreasing returns to scale (IRS), then there are decreasing returns to scale.

The other criterion that was used to determine the type of returns to scale presented by each of the sugar mills is the so-called local elasticity of scale. Since the efficient production frontier in the case of the DEA is a construction by ‘pieces’ with ‘corners’ and not a smooth curve as in the case of the efficient frontier of the production function of neoclassical microeconomics, it is not possible to have a single point estimate, so the local elasticity on the left (upper limit) and the local elasticity on the right (lower limit) are estimated.

According to Hackman (2008), elasticity of scale measures the percentage change in output or production in response to a 1% change in all inputs or factors of production. Hackman (2008) points out that when all inputs change proportionally, the scale of operation is said to change. In the specific case of the DEA, the demonstration of how the elasticity of scale is obtained theoretically is mainly found in Førsund and Hjalmarsson (2004); Førsund *et al* . (2007) .

The dataset used to estimate the elasticity of scale, returns to scale and efficiency indicators are those reported by CONADESUCA (2017) . The data correspond to the 2009-2010 harvest, as they are the most complete for the 54 mills that operated in that harvest and for which there is complete information. The software used to estimate the data envelopment analysis (DEA) model was ‘benchmarking’ (Bogetoft, 2020), which works under the non-commercial program CRAN-R 4.1.

Results and discussion

The variables used in the study are shown in Table 1 . In this regard, it is important to note that the electricity produced is that reported directly by CONADESUCA (2017) in kilowatt-hours, so it is considered an output. In the case of the total energy consumed, it corresponds to the conversion into a common unit of kilowatt-hours of oil and bagasse burned during the cane milling process to obtain sugar. The conversions were made following Rein (2007).

Table 1. Variables used in the study.

Variable	Units	Type
Sugar produced per hectare	(t ha^{-1})	Output
Electricity produced	(kW-h)	Outputt
Total energy consumed	(kW-h)	Input
Haulage vehicles	Units	Input
Gross milled cane	(t)	Input
Cutters	Day laborers	Input
Cutting fronts	Units	Input
Lost harvest time	(h)	Input

CONADESUCA (2017).

The amount of electricity that some mills buy from the Federal Electricity Commission (CFE) was added to the amount resulting from the burning of oil and bagasse, thus obtaining the referred variable. However, since this variable was calculated for a specific consulting project, its respective descriptive statistics are not included, even though the values by mill were used to run the programming models and to calculate the efficiency and scale indicators. Table 2 shows the main statistical data of the cross section corresponding to the 2009-2010 harvest reported by CONADESUCA (2017) .

Table 2. Descriptive statistics of the variables used.

Variable	Average	Maximum value	Minimum value	Standard deviation
Sugar produced per ha	7.5	15.4	2.5	2.9
Electricity produced	12 226 600	42 659 300	11 191	9 266 719
Haulage vehicles	272	1 272	32	222
Net milled cane	733 452	2 268 889	14 987	483 874
Cutters	1 162	3 514	76	772
Cutting fronts	22	102	2	21
Lost harvest time	752	1 747	118	308

Adapted from CONADESUCA (2017).

The DEA model that was run in this work was the input-oriented multiplicative model, the radial distance function was used for the calculation of the indicators of overall efficiency, pure efficiency, scale efficiency and elasticity of scale. In the study, three groups of mills were identified according to the type of returns to scale they presented. The first group consisted of 21 sugar mills that had constant returns to scale (39.6%), the second group had three mills with decreasing returns to scale (7.5%) and the third group consisted of 28 mills with increasing returns to scale (52.8%). Table 3 shows the sugar mills belonging to the first group.

Table 3. Mills with constant returns to scale.

Mill	Efficiency overall technical	pure technical	of scale	Elasticity of scale upper limit	lower limit
El Dorado	1	1	1	Infinite	0.03
Calipam	1	1	1	Infinite	0.21
Avance Regional	1	1	1	Infinite	0
Melchor Ocampo	1	1	1	Infinite	0.08
Lázaro Cárdenas	1	1	1	Infinite	0.25
Constancia	1	1	1	Infinite	0
Los Mochis	1	1	1	Infinite	0.66
Huixtla	1	1	1	45.08	0.79
San Rafael de Pucté	1	1	1	6.28	0.66
Pedernales	1	1	1	3.98	0.25
Central Casasano	1	1	1	3.7	0.01
Tamazula	1	1	1	3.3	0.04
El Potrero	1	1	1	2.65	0.3
Tres Valles	1	1	1	2.62	0
Adolfo López Mateos	1	1	1	2.6	0.15
Pujiltic	1	1	1	2.23	0.05
San José de Abajo	1	1	1	2.07	0.9
Atencingo	1	1	1	2.06	0
Puga	1	1	1	1.87	0.36

Mill	Efficiency overall technical	pure technical	of scale	Elasticity of scale upper limit	lower limit
San Miguel del Naranjo	1	1	1	1.71	0.05
Aarón Sáenz Garza	1	1	1	1.52	0.25

As can be seen, in the group of 21 mills with constant returns to scale are those mills that are on the efficient production frontier. The fact that the pure efficiency for the mills of this group is equal to the unit shows that these DMUs have achieved optimal performance in their production process because they perform the best productive practices, optimally managing and assigning the inputs or factors of production over which they have control.

The optimal performance of the mill is indicative that in the field there may be good coordination and understanding between the organizations of sugarcane suppliers, both of the ejido regime and the smallholders and sugar mills for the timely supply of sugarcane in plant for milling. Table 3 also shows that, in the case of all optimally operating mills, the scale efficiency is equal to the unit.

The finding that the mills in Table 1 operate at their optimum scale using the DEA is confirmed by the elasticity of scale. As can be seen, for all mills the elasticity of scale on the left or upper limit is greater than the unit. This implies that if all inputs were increased by 1%, the increase in production would be proportionally greater than 1%. That is, on the left in the vicinity of the corner point of the efficient frontier, each DMU is at the optimal stage of production.

In the case of the elasticity of scale on the right, or lower limit, it is less than the unit. This is indicative that if all inputs were increased by 1%, the increase in output obtained would be proportionally less than 1%. Put another way, on the right in the vicinity of the corner point of the efficient frontier, each DMU is at the stage of production that is no longer optimal. On the other hand, in Table 4 are the five mills with decreasing returns to scale.

Table 4. Mills with decreasing returns to scale.

Mill	Efficiency technical	pure technical	of scale	Elasticity of scale upper limit	lower limit
El Higo	0.98	1	0.98	0.79	0.21
Emiliano Zapata	0.98	1	0.98	0.87	0.04
La Gloria	0.98	0.98	0.99	0.99	0.56
Plan de Ayala	0.94	0.94	1	1.05	0.92
Plan de San Luis	0.93	0.95	0.98	1.19	0.62

The analysis in the case of this second group of sugar mills is more complex. It was observed that, for the mills El Higo and Emiliano Zapata, pure efficiency, that due to the best productive and resource management practices that the respective DMU has, is equal to the unit. However, the efficiency due to their size, efficiency of scale, is less than the unit, therefore, the diseconomies of scale that they present are due to their size. In the case of the mills La Gloria and Plan de San Luis, their inefficiency is due both to the productive and administrative (management) practices carried out and their size.

In the case of the ejido La Gloria, both pure efficiency and scale inefficiency are less than the unit, so their inefficiency is due to both productive practices and their size. The inclusion of the five mills in Table 4 is confirmed by the elasticity of scale. Although in the case of the elasticity of scale on the right for the mills Plan de Ayala and Plan de San Luis, it is slightly greater than the unit, this is very low compared to the average elasticity of scale on the right for the other mills (5.8).

For three other mills (El Higo, Emiliano Zapata, La Gloria) both the elasticity of scale on the right (upper limit) and the elasticity of scale on the left (lower limit) are less than the unit, which confirms that these mills indeed show decreasing returns to scale and are operating suboptimally. The third group of sugar mills, identified with the help of the software used, corresponds to those that, although they are operating suboptimally, if they increase the size of their plant, they could improve their efficiency, since they present increasing returns to scale, as can be seen in Table 5 .

Table 5. Mills with increasing returns to scale.

Mill	Efficiency			Elasticity of scale	
	overall technical	pure technical	of scale	upper limit	lower limit
Azsuremex	0.86	1	0.86	inf	1.26
José María Morelos	0.82	1	0.82	inf	1.94
El Carmen	0.55	0.94	0.58	inf	1.14
El Refugio	0.51	0.78	0.64	276.12	11.86
Nuevo San Francisco	0.49	0.91	0.54	189.57	4.06
Santa Rosalía	0.57	0.92	0.62	129.26	7.16
San Pedro	0.55	0.9	0.61	109.47	6.21
Central La Providencia	0.58	0.82	0.71	103.7	5.93
Central Progreso	0.53	0.73	0.72	25.6	6.22
San Miguelito	0.74	0.88	0.84	20.15	6.3
El Molino	0.7	0.8	0.87	19.7	4.54
San Francisco Ameca	0.72	0.91	0.79	19.24	7.84
El Mante	0.59	0.84	0.7	18.63	2.26
El Modelo	0.73	0.88	0.83	16.65	6.87
Cuatotolapam	0.68	0.88	0.77	15.43	3.59
Santa Clara	0.87	0.98	0.89	13.27	4.74
Central Motzorongo	0.74	0.83	0.89	12.12	3.11
San Nicolás	0.76	0.88	0.86	11.31	2.13
Presidente Benito Juárez	0.69	0.85	0.81	10.6	2.01
Alianza Popular	0.72	0.77	0.94	8.75	2.39
San Cristóbal	0.98	1	0.98	4.52	1.19
Mahuixtlán	0.72	0.87	0.83	3.05	1.78
Bellavista	0.79	0.92	0.86	2.95	1.74

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Mill		Efficiency		Elasticity of scale	
	overall technical	pure technical	of scale	upper limit	lower limit
La Joya	0.74	0.84	0.87	2.75	1.22
Tala	0.81	0.93	0.87	2.55	1.1
Pánuco	0.8	0.86	0.93	2.01	1.19
La Margarita	0.85	0.85	0.99	1.88	1.51
Queseria	0.95	0.96	0.99	1.19	0.91

Except for the mills Azsuremex, José María Morelos and San Cristóbal, the other 25 sugar mills in Table 5 could also improve their efficiency not only through an expansion of their plant, but also by improving their pure efficiency; that is, the efficiency that comes from improving their productive input management practices, and from reaching the most economically convenient agreements with the organizations of sugarcane suppliers in the area, to guarantee the supply in a timely manner during the respective harvest period.

When analyzing individually some of the mills of Table 5 , on the side of the economy of scale, it is possible to observe that in the group of these DMUs, some have a scale efficiency below 70%. These mills are Nuevo San Francisco, El Carmen, San Pedro, Santa Rosalía and El Refugio, whose scale efficiency was 54%, 58%, 61%, 62% and 64%, respectively. If these mills expand the size of their plant by increasing all their inputs to obtain standard sugar, their overall efficiency could improve considerably.

Overall efficiency could also be improved in this group of mills if their pure efficiency were improved; that is, the efficiency derived from the improvement in their productive practices. For example, for the mills Central Progreso, Alianza Popular and El Refugio, their pure efficiency is 73%, 77% and 78%, respectively. In these mills, if their productive practices are improved, their pure efficiency will improve and therefore their overall efficiency.

The 2016-2017 harvest was selected as a point of comparison because it is the last publication of CONADESUCA (2017) in which the data of the field and milling variables of the sugar mills appear disaggregated at the DMU level. Table 6 shows the three mills that stopped operating between the 2009-2010 and 2016-2017 harvests.

Table 6. Mills closed between the 2009-2010 and 2016-2017 harvests.

Mill		Efficiency		Elasticity of scale	
	technical	pure technical	of scale	upper limit	lower limit
Avance Regional	1	1	1	Infinite	0
Los Mochis	1	1	1	Infinite	0.66
Nuevo San Francisco	0.49	0.91	0.54	189.57	4.06

Table 6 shows that for the 2009-2010 harvest, the mills Avance Regional and Los Mochis operated at their optimum scale, since their overall efficiency and pure technical efficiency are equal to the unit; that is, these DMUs operated in the aforementioned harvest on the efficient production frontier.

According to CONADESUCA (2017) data, the mill Nuevo San Francisco stopped producing and was closed in 2012. However, according to information from the microsite of the mill itself, after a series of circumstances where the struggle of the personnel who worked in said mill before its closure stands out, said mill was reopened and restarted operations at the beginning of 2021. When comparing the results obtained with the DEA for the average technical efficiency by country, since no study of the reviewed reports results at the DMU level, data were found for three countries. In the case of Mexico, two studies are reported, as can be seen in Table 7 .

Table 7. Technical and scale efficiency of sugarcane agroindustry in several countries.

Region	Overall efficiency	Pure efficiency	Scale efficiency	Study period or harvest	Orientation
Indonesia	0.899	0.937	0.96	2018	Input
Philippines	0.7431	0.777	0.9582	2001	Input
Mexico:					
Scenario 1	na	na	0.8895	2015/2016	Input
Scenario 2	na	na	0.9653	2015/2016	Input
Mexico	0.8515	0.9382	0.9004	2009/2010	Input
Kenya	0.849	0.8995	0.9474	2011/2017	Output

Scenario 1= unmechanized harvesting; scenario 2= mechanized harvesting; na= not available.

For Mexico, Escobedo *et al* . (2019) report the scale efficiency for the 2015-2016 harvest under two scenarios: mechanized harvesting and unmechanized harvesting. The criterion for considering the harvesting as mechanized was the incorporation of a sugarcane harvesting machine to the second scenario. The results of the study by Escobedo *et al* . (2019) show that, when incorporating a harvesting machine, the scale efficiency went from 88.95% to 96.53%.

However, it should be borne in mind that Escobedo’s work corresponds to the 2015-2016 harvest and that of the present work to data from the 2009-2010 harvest. When comparing the average scale efficiency of the sugarcane agroindustry of Mexico against that of Indonesia (Escobedo *et al* ., 2019 ; Setyaningrum, 2020), it was observed that that of the latter is higher by 5.96%; that is, there is a greater efficiency of the sugar agroindustry of Indonesia than in that of Mexico.

The same is true when comparing the scale efficiency of Mexico in the present study against the scale efficiency of the Philippines (Padilla and Nuthall, 2009); Kenya (Mulwa, 2009), the efficiency of scale of Mexico is lower than that of the results cited in the respective sources. Additionally, when comparing the pure efficiency of Mexico against the other countries, it is observed that Mexico and Indonesia have, in practice, the same efficiency (93%), while such efficiency of Mexico is above the Philippines and Kenya, whose pure efficiency is 74.3% and 84.9%, respectively.

Conclusions

Mexico is a self-sufficient country in the production of granulated sugar to meet its domestic demand, despite the technological backwardness that official documents and many academic studies still affirm the sugarcane agroindustry in Mexico has. It was found that, during the 2009-2010 harvest, of the 53 sugar mills that were included in the study, 21 (38.9%) presented constant returns to scale, so they were working optimally with the size of the plant they had at that time.

Another 28 mills (51.9%) were operating with increasing returns to scale, so if they had expanded the size of their plant, their production would have increased more than proportionally than all the inputs together and at the same time would have increased. In addition, it was found that only five sugar mills operated with decreasing returns to scale (9.3%), that is, even if they had expanded the size of the plant and improved their production practices and processes, their efficiency of scale, pure efficiency and overall efficiency would have improved very little or their diseconomies of scale and inefficiency could even have increased.

In other words, until just over a decade ago, there was room for improving the productivity and efficiency of the sugarcane agroindustry. The fact that the country has been observing the self-sufficiency of granulated sugar for more than a decade and even with surpluses for export is indicative that, despite its repeated technological backwardness, it may not be such, but that the

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economic, social, institutional and other problems that the Mexican countryside is experiencing may be affecting the optimal performance of the sugarcane agroindustry in Mexico.

Bibliography

1 Aigner, D.; Lovell, K. and Schmidt, P. 1977. Formulation and estimation of stochastic frontier production function models. J. Econ. 6(1):21-37.

2 Banker, R. D.; Charnes, A. and Cooper, W. W. 1984. Some models for the estimation of technical and scale inefficiencies in data envelopment analysis. Manage. Sci. 30(9):1078-1092.

3 Bogetoft, P. 2020. Benchmarking with DEA and SFA. R package version 0.29. https://cran.r-project.org/web/packages/Benchmarking/index.html .

4 Bröchner, J. 2017. Measuring the productivity of facilities management. J. Facil. Manag. 15(3):1-35.

5 CEMA. 2017. Compañía editora del manual azucarero mexicano. Manual azucarero mexicano. Ed. SA de CV. Ciudad de México. 487 p.

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

7 Charnes, A.; Cooper, W. W. and Rhodes, E. L. 1978. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2(6):429-444.

8 CONADESUCA. 2017. Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar. 6toinforme estadístico del sector agroindustrial de la caña de azúcar en México. Ciudad de México.

9 CONADESUCA. 2020b. Comité Nacional para el Desarrollo sustentable de la Caña de Azúcar (2020). 7moinforme estadístico del sector agroindustrial de la caña de azúcar en México. Ciudad de México, México.

10 Escobedo, C, O. A.; Valdivia, A. R.; Sandoval, R. F.; Hernández, O. J. y Gutiérrez, G. F. G. 2019. Análisis de la eficiencia técnica de la agroindustria de la caña de azúcar en México con el análisis envolvente de datos. Rev. Mex. Econ. Agríc. Rec. Natur. 12(1):77-91.

11 Farrell, M. J. 1957. The Measurement of productive efficiency. J. R Stat. Soc. 120(3):253-290.

12 FIRA. 2016. Fideicomisos Instituidos en Relación a la Agricultura. Panorama agroalimentario. Azúcar. Morelia, Michoacán, México.

13 Førsund, F. R. and Hjalmarsson, L. 2004. Calculating scale elasticity in DEA models. J. Oper. Res. Soc. 55(10):1023-1038.

14 Førsund, F. R.; Hjalmarsson, L.; Krivonozhko, V. E. and Utkin, O. B. 2007. Calculation of scale elasticities in DEA models: direct and indirect approaches. J. Prod. Anal. 28(1):45-56.

15 Hackman, S. T. 2008. Production economics. Integrating the microeconomic and engineering perspectives. Springer. Berlin, Germany. 522 p.

16 Meeusen, W. and Van-Broeck, J. 1977. Efficiency estimations from Cobb-Douglas production functions with composed error. Inter. Econ. Review. 18(2): 435-44.

17 Mulwa, M. R.; Emrouznejad, A. and Murithi, F. M. 2009. Impact of liberation on efficiency and productivity of sugar industry in Kenya. J. Econ. Studies. 36(3):250-264.

18 Padilla, F. M. D. and Nuthall, P. L. 2009. Technical efficiency in the production of sugar cane in central negros area, philippines: an application of data envelopment analysis. J. Int. Soc. Southeast Asian Agric. Sci. 15(1):77-90.

DOI: https://doi.org/10.29312/remexca.v14i5.2999

19 Rasmussen, S. 2011. Production economics. The basic theory of production optimization. Springer, New York, NY. 287 p.

20 Rein, P. 2007. Cane sugar engineering. Verlag Dr. Albert Bartens. Berlin, Germany. 746 p.

21 Setyaningrum, W F.; Ekowati, T. and Kristanto, A. 2020. The efficiency of sugarcane (*Saccharum officinarum*) farms using the dea (data envelopment analysis) approach in purworejo regency. Agrisocionomics. 4(2):330-335.

22 Santiago, Z. I. M.; Martínez, D. M. A.; Cuevas, A. C. M.; Valdivia, A. R.; García, H. M. I. y Hernández, T. J. 2021. Productividad y cambio tecnológico en la agroindustria de la caña de azúcar en México. Rev. Mex. Cienc. Agríc. 12(6):1005-1017. Doi: https://doi.org/10.29312/remexca.v12i6.2692 .

23 SIAP. 2020. Servicio de Información Agroalimentaria y Pesquera. Anuario estadístico de la producción agrícola. https://nube.siap.gob.mx/cierreagricola/ .

24 Valdivia, A. R.; Cuevas, A. C. M.; Vázquez, M. J. S.; García, H. M. I.; Santiago, Z. I. M. y Garay, J. A. S. 2022. Análisis de la eficiencia y retornos de escala de los ingenios azucareros de México. Rev. Mex. Cienc. Agríc. 13(1):141-153. Doi: https://doi.org/10.29312/remexca.v13i1.2639 .

25 Zhu, J. 2003. Quantitative models for performance evaluation and benchmarking: data envelopment analysis with spreadsheets and DEA Excel solver. Kluwer Academic Publisher. Boston, USA. 312 p.

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