A methodological approach to sugar mill diversification and conversion

Enfoque metodológico de diversificación y reconversión de ingenios azucareros

N. Aguilar[1], G. Galindo[2], C.Contreras[3], J.Fortanelli[4]

ABSTRACT

Sugar industry diversification is complex, being constrained by biophysical and socioeconomic conditions. Ongoing work has shown the sugarcane industry's potential as biorefinery or its sustainable use by offering products as raw material. However, few studies have studied how such potential could be achieved by promoting a conventional sugar mill through integrating its indicators for developing an efficient diversified processing plant which would contribute towards fossil energy saving and competitiveness. This paper presents a conceptual framework for analysis based on existing knowledge regarding sugar industry state-of-the-art for evaluating diversification, using analytical hierarchy process (AHP) as a tool for analysing complex systems, identifying alternatives to the current situation and discussing them to facilitate collective decision-making. Sugar mill AHP scores enabled discussion about the variables most affecting sugar mill diversification (0.332 factory yield, 0.327 sugar mill products and 0.121 sugarcane quality). The results serve as a useful guidance for formulating strategies for the optimum use of by-products in a sugar mill while maximising benefits to modify/convert a traditional sugar mill to a so-called bio-refinery.

Keywords: Sugar mill, AHP, analytic hierarchy process, diversification.

RESUMEN

La diversificación de la industria azucarera es compleja y se ve limitada por condiciones biofísicas y socioeconómicas. Muchos trabajos han demostrado su potencial como biorrefinería y la utilización sostenible de los subproductos como materia prima. Sin embargo, pocos estudios se ha focalizado a través de la integración de indicadores productivos de un ingenio azucarero y cómo este potencial podría lograr transformar un ingenio azucarero convencional en una eficiente planta diversificada que contribuya a reducir el consumo de energía fósil y alcanzar la competitividad. Este trabajo presenta un marco de análisis o metodología basada en el conocimiento existente sobre la industria azucarera o el estado del arte, con la finalidad de evaluar la diversificación mediante el proceso de jerarquías analíticas (AHP) como una herramienta adecuada para el análisis de sistemas complejos, la identificación de alternativas y su discusión de manera que facilite la toma de decisiones colectivas. El análisis AHP obtenido en este estudio ofrece una discusión acerca de las variables que explican la capacidad para diversificar los procesos en un ingenio azucarero (rendimiento de fábrica: 0.332, productos derivados del ingenio azucarero: 0.327 y calidad de materia prima o caña de azúcar: 0.121). Los resultados obtenidos sirven de guía en la formulación de estrategias para la utilización óptima de los recursos derivados de un ingenio azucarero, mientras que la maximización de sus beneficios, para diversificar o reconvertir ingenios azucareros en biorrefinerías.

Palabras clave: ingenio azucarero, AHP, diversificación.

[1] Noé Aguilar Rivera. *Affiliation:* Universidad Veracruzana. PhD in Environmental sciences, Universidad Autónoma de San Luis Potosí, Mexico. MSc. in Forestal product sciences, Universidad de Guadalajara, Mexico. BSc. in Chemical Engineering, Instituto Tecnológico de Orizaba Veracruz, Mexico. E-mail: naguilar@uv.mx

[2] María Guadalupe Galindo Mendoza. Affiliation: Universidad Autónoma de San Luis Potosi, Mexico. Doctor Philosophy and letters Faculty, UNAM, Mexico. Master in Philosophy and letters Faculty, UNAM, Mexico. Geography licentiate Philosophy and letters Faculty UNAM, Mexico. E-mail: ggm@uaslp.mx

[3] Carlos Contreras Servín. Affiliation: Universidad Autónoma de San Luis Potosi, Mexico. Doctor Philosophy and letters Faculty, UNAM, Mexico. Master in Philosophy and letters Faculty, UNAM, Mexico. Geography licentiate Philosophy and letters Faculty UNAM, Mexico. E-mail: coser@uaslp.mx

4 Javier Fortanelli Martínez. Affiliation: Universidad Autónoma de San Luis Potosi, Mexico. Doctor Agronomy Faculty, Universidad Autónoma de San Luis Potosi, Mexico. Master in Colegio de Posgraduados en Ciencias Agrícolas, Montecillo, Mexico. Licenciature in Escuela de Agronomía. E-mail: fortanel@uaslp.mx

Introduction

Agroindustry sugarcane represents a production sector which has worked with a single product, sucrose or table sugar, resulting from operations in a sugar mill exclusively processing a raw material, sugarcane (Saccharum officinarum L.), from a monoculture. FAOSTAT (2009) reported that sugarcane is produced in over 130 countries (having varying economic development) worldwide and is consumed locally in all of them at various levels (per capita consumption of sugar kg / inhabitant / year), the world average being 22.64 (Figure 1). The major producers are Brazil (20.8%), India (14.7%), China (7.0%), the USA (4.6%), Thailand (3.7%), Mexico (3.6%) and Australia (3.1%).

The economic challenges facing the global sugar industry are volatile world trade sugar prices (Figure 2) and the diversification of sugarcane monoculture production structure and sugar mill by-products (bagasse, molasses, vinasse, filter sludge and ashes) for improving productivity and competitiveness by using existing equipment, infrastructure and increasing the specialisation resulting from potential demand for sugarcane derivatives worldwide (Aguilar *et al.*, 2009, 2010).
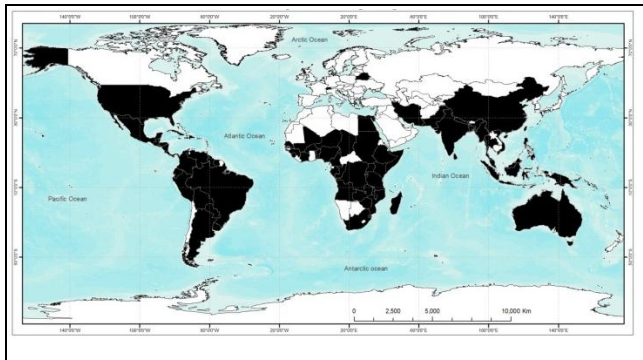

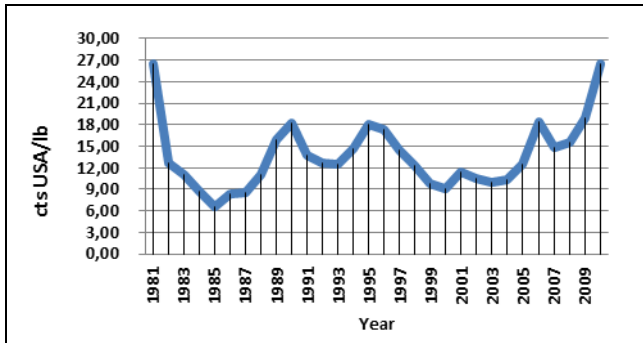Figure 1. Sugarcane producing countries (FAOSTAT, 2009)

Figure 2. . International refined sugar price (data from London International Financial Futures and Options Exchange, LIFFE)

However, sugar industry diversification (Figure 3) is highly complex; it has been evaluated since 1970 as being a viable technical-economic alternative to offset international sugar price volatility by decreasing production costs and environmental impact while converting by-products into raw materials for new production cycles (Contreras *et al.*, 2009; Renouf, 2007; Johannesburg, 2005; Lodi, 2005 and Galvez, 2000).

Analysing diversification projects must be based on scientific knowledge regarding co-products, energy and material balance and the sugarcane derivative trade on the complexity assumed for incorporating and integrating agroindustrial factors and variables using the biorefinery concept for discussing their possible effects (D'Hont *et al.*, 2008; Brumbley 2007; Birch, 2007; Edye, 2006; Morandini, 2006; Avram, 2005).

Such conceptualisation should form the starting point for studying diversification and identifying constraints and the specific weighting of each determining factor in sugar mills; this implies designing fresh decision-making methodologies, such as multicriteria evaluation (MCE). This study was aimed at developing a methodology for determining sugar mills' capacity to diversify their base production (sucrose), as a diversification index, by using the analytic hierarchy process (AHP) multicriteria method
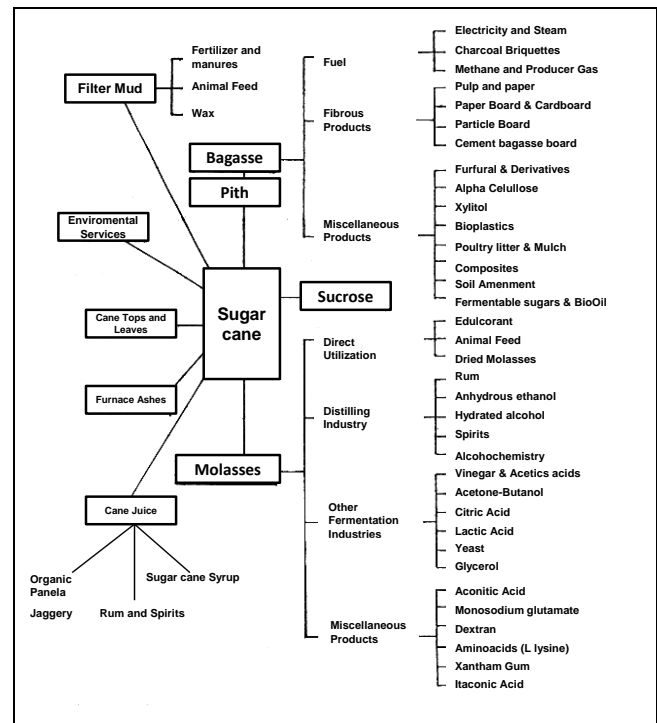

Figure 3. . Sugar industry by–products and derivatives (adapted from Paturau, 1989)

Materials and Methods

MCE is based on weighting and compensating for variables and aptitudes determining decision theory-related factors (Gomez, 2006). A multicriteria problem involves a discrete number of alternatives where A is a finite set of n alternatives or feasible actions, G is the set of m evaluation functions gi, i = 1,2, ..., m associated with the evaluation criteria. If A is an alternative, gi (A) is their assessment and i criterion can be represented in a matrix P of m rows and n columns (evaluation table or impact matrix) whose elements pij (i = 1,2, .. ., m, j = 1,2, ..., n) represent the evaluation of alternative j in criterion i (Falconi, 2004).

AHP is supported by reciprocal judgments and element homogeneity in a complex multivariable problem compared to the same order of magnitude and hierarchical structure to prioritise their relative importance in production systems (Freitas, 2006 and Saaty, 1990). It has been used in sugarcane variety selection (Zhong *et al.*, 2009), in designing strategies to increase competitiveness (Akli, 2009; Castellanos, 2007; Nagesha, *et al.*, 2006; Abreu, 2004), sugarcane area management (Diogo *et al.*, 2007; Qureshi, 2003) and bioethanol and bioenergy projects (Turcksin, 2010; Hilmola *et al.*, 2010; Lapola *et al.*, 2010; Tienwong, 2009; Lamparelli, 2009; Junqueira *et al.*, 2009; Silva, 2009, Quintero *et al.*, 2008; Papalexandrou, 2007).

The study involved variables or factors according to international sugar organisation (ISO, 2005) standards for sugar industry competitiveness and diversification: sugar mill yield (%), sucrose recovery rate (%), total time loss (%), sugarcane quality (% sucrose), external electricity (kWh / t. cane), external fuel consumption (oil) oil L / t.cane and produced sugarcane derivatives (raw, muscovado, refined, ethanol, electricity, compost, fertirigation, rum, spirits, etc.).

Such variables or factors provide a priori information about the sector's ability to diversify, including optimal indexes for interna-

tional comparative analysis (benchmarking), industry dynamics and weighting each variable or techno-economic indicator's relative importance in analysing diversification when considering sugar mill capacity, raw material quality and energy balance (ISO, 2005; Zimmermann, 2002; Banerjee, 2004).

Each factor's relative importance was evaluated by building a multicriteria AHP pairwise comparison matrix and then using such matrix for assigning a different value (weighting) to individual factors or constraints. Each possible pair was compared and qualified by applying a continuous hierarchical scale of 17 relative importance factors (Figure 4).
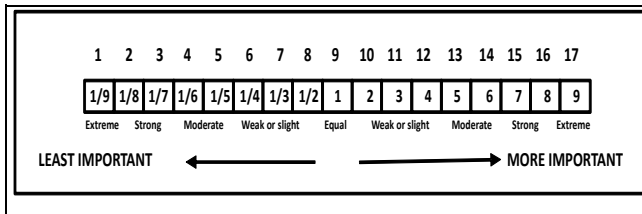

Figure 4. hierarchical scale consisting of 17 relative importance factors for constructing the comparison matrix between factor pairs or variable decision (Diaz, 2000)

AHP evaluates paired matrix error or inconsistency for overall sets of alternative priorities; less than 10% (CI index <0.1) is considered acceptable and robust (Sipahi 2010; Berumen 2007; Aguarón *et al.*, 2003; Saaty, 1990).

Results and Discussion

Tables 1 and 2 show the pairwise matrix and weightings obtained using Expert Choice 11.5 software AHP evaluation module for each factor.

Table 1. Pairwise comparison matrix

Factor	Sugar mill yield	Sucrose recovery rate	Total time loss	Sugarcane quality	External electricity	External fuel	Sugarcane derivatives
Sugar mill yield	1	6	5	4	8	8	1
Sucrose recovery rate	$1/6$	1	2	2	6	4	5
Total time loss	$1/5$	$1/2$	1	2	7	3	5
Sugarcane quality	$1/4$	$1/2$	$1/2$	1	6	5	4
External electricity	$1/8$	$1/6$	$1/7$	$1/6$	1	2	9
External fuel	$1/8$	$1/4$	$1/3$	$1/5$	$1/2$	1	9
Sugarcane derivatives	1	$1/5$	$1/5$	$1/4$	$1/9$	$1/9$	1

Sugar mill yield (%) and the number of goods or sugarcane derivatives produced (raw, muscovado, refined, ethanol, electricity, compost, fertirigation, rum, spirits, etc) had greater weighting than whole factors, since they implied greater sugar mill capacity to transform raw material into sucrose and by-products (molasses, bagasse, filter sludge, ashes and vinasse) for energy and other products (cogeneration, ethanol, compost, refined sugar, musco-

vado, organic waste, etc.) along with conventional raw or refined sugar and facilities and technical knowledge (learning curve or know-how) when producing sugarcane and its derivatives. The next most important factors were sugarcane quality (% sucrose, % fibre) and sucrose recovery rate (%), their importance being directly related to sugar cane production and intrinsic productivity. Sucrose recovery rate (%) was related to core technology and/or the obsolescence of the equipment being used for handling raw materials, representing external electricity and fuel consumption both by t / cane resulting from energy diversification regarding external power.

Table 2. Sugar mill diversification factor weighting (consistency index = 0.06)

Constraints on sugar mill diversification	Weighting
Sugar mill yield (%)	0.332
Sugarcane derivatives (raw, muscovado, refined, ethanol, electricity, compost, fertirigation, rum, spirits, etc)	0.327
Sugarcane quality (% sucrose)	0.121
Sucrose recovery rate (%)	0.092
Total time loss (%)	0.077
External electricity (kWh / t. cane)	0.027
External fuel consumption (oil L / t. cane)	0.025
Total	1.000

Regarding the weighting of each factor in Tables 1 and 2, a sugar mill evaluation instrument or chart was prepared (Table 3) according to Ahumada (2009), Yamba (2008), ISO (2005), Trujillo (2002) and Zimmermann *et al.*, 2002 determining the weighting or relative importance by hierarchical level and threshold for making technical decisions concerning diversifying the sugar industry (high, medium, low and very low diversification index).

Table 3. Sugar mill assessment matrix by technical ability level
(1 = high capacity, 0 = no diversification capacity)

Constraints on sugar mill diversification	Unit	Score				Final weighting
		High (1)	Medium (0.75)	Low (0.50)	Very low (0.25)	
Sugar mill yield	%	>12	12-11.5	11.5-10.5	<10.5	
		0.332	0.249	0.166	0.083	
Sucrose recovery rate	%	>85	85-83	83-80	<80	
		0.092	0.069	0.046	0.023	
Total time loss	%	<10	10-15	15-20	>20	
		0.077	0.05775	0.0385	0.01925	
Sugarcane quality (raw material)	% sucrose	>14.5	14.5-13.5	13.5-12.5	<12.5	
		0.121	0.09075	0.0605	0.03025	
External electricity	KWH/t. cane	0	0-0.5	0.5-1	>1	
		0.027	0.02025	0.0135	0.00675	
External fuel consumption	Oil L / t. cane	0	0-2	2-5	>5	
		0.025	0.01875	0.0125	0.00625	
Sugarcane derivatives (raw, muscovado, refined, ethanol, electricity, compost, fertirigation, rum, spirits, etc)	#	>4	3	2	1	
		0.327	0.24525	0.1635	0.08175	
TOTAL						

The aforementioned methodology could be used as a tool for supporting decision-making in planning sugar mill diversification. Variables, factors and constraints needing intensive study were identified and may be reproduced in other settings and enriched by including new criteria and constraints, avoiding subjective information derived from sector statistics (restrictions on indicators traditionally used for highlighting the sugar sector's national and regional importance) and speculative action for positively and systematically managing controllable sugar production factors .

Conclusions

A <0.1 IC established that the independent variables used were sufficient for an a priori explanation of dependent variable "sugar mill diversification capacity." This method provided indicator-based synthesis (index diversification), this being an advantage since it significantly reduced the amount of data to be analysed and was not simply an aggregation of indicators, each therefore being weighted according to their relative importance and having real dimensions applicable to any sugar mill worldwide

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