EVALUATION OF SUSTAINABILITY INDICATORS OF THE SUGARCANE AGROECOSYSTEM IN SIHOCHAC, CHAMPOTÓN, CAMPECHE, MÉXICO †

[EVALUACIÓN DE INDICADORES DE SUSTENTABILIDAD DEL AGROECOSISTEMA DE CAÑA DE AZÚCAR EN SIHOCHAC, CHAMPOTÓN, CAMPECHE, MÉXICO]

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SUMMARY

Background: Currently, agroecosystems (AES) face problems related to climate change, soil erosion, environmental pollution, and resource degradation that directly impact sustainability. **Objective:** To understand the degree of sustainability of the sugarcane agroecosystem of the community of Sihochac, Champotón, Campeche, Mexico, through the analysis and evaluation of economic, environmental and sociocultural indicators. **Methodology:** The MESMIS method was used to define the indicators corresponding to each dimension. The information from each was gathered based on a sample of 70 farmers, calculated through the finite population formula; a questionnaire with closed questions was applied and answers with a scale of 0 to 4. **Results:** The sociocultural indicators obtained the highest value with 2.32, followed by the economic with 2.14, and lastly, the environmental with 0.57. The General Sustainability Index (GSI) obtained was 1.68, which indicates that the sugarcane agroecosystem is not sustainable. **Implications:** The sugarcane farmers manage their agroecosystems with various conventional methods, so they require using more sustainable practices to reduce the environmental impact on this crop. **Conclusions:** Because the sugarcane AES is not sustainable, it is necessary to implement conservation measures, for example, using varieties that are more resistant to pests and diseases which require less synthetic chemical products and promoting the use of organic fertilizers, as well as fostering social relationships and fairer and more solidary support both for farmers and for representatives of sugarcane-growing groups.

Key words: Sustainable agriculture; Equity; *Saccharum officinarum*; Sustainability Indicators; MESMIS.

RESUMEN

Antecedentes: Actualmente los agroecosistemas (AES) enfrentan problemas relacionados con el cambio climático, erosión de suelos, contaminación ambiental y degradación de recursos que repercuten directamente en la sustentabilidad. **Objetivo:** Conocer el grado de sustentabilidad del agroecosistema cañero de la comunidad de Sihochac, Champotón, Campeche, México, a través del análisis y evaluación de indicadores económicos, ambientales y socioculturales. **Metodología:** Se utilizó el método MESMIS para definir los indicadores correspondientes a cada dimensión. La información de cada uno se recopiló con base en una muestra de 70 productores, calculada mediante la fórmula de poblaciones finitas; se aplicó un cuestionario con preguntas cerradas y respuestas en una escala de 0 a 4. **Resultados:** Los indicadores socioculturales obtuvieron el valor más alto con 2.32; seguido por los económicos con

† *Submitted October 28, 2024 – Accepted April 9, 2025. http://doi.org/10.56369/tsaes.5935*

ISSN: 1870-0462.

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2.14 y, por último, los ambientales con 0.57. El Índice de Sustentabilidad General (ISG) obtenido fue de 1.68, lo que indica que el agroecosistema cañero no es sustentable. **Implicaciones:** Los productores cañeros manejan sus agroecosistemas con diversos métodos convencionales, por lo que requieren utilizar prácticas más sustentables para reducir el impacto ambiental en este cultivo. **Conclusiones:** Debido a que el AES cañero no es sustentable, es necesario implementar medidas de conservación, por ejemplo, variedades más resistentes a plagas y enfermedades que requieran menor cantidad de productos químicos sintéticos y promover el uso de abonos orgánicos, así como fomentar las relaciones sociales, apoyos más justos y solidarios tanto para productores como a representantes de grupos cañeros.
Palabras clave: Agricultura sustentable; Equidad; *Saccharum officinarum*; Indicadores de Sustentabilidad; MESMIS.

INTRODUCTION

Sustainability is a concept proposed by the former Swedish minister of the environment, Gro Harlem Brundtland, when she presented the Our Common Future report at the 1992 Conference on Environment and Development in Rio de Janeiro; it is defined as the production of goods and services for the satisfaction of present and future human needs that guarantee a better quality of life for the population in general, with clean technologies, in a non-destructive relationship with nature and the participation of citizens in decision making, improving environmental conditions and using natural resources within the load capacity of ecosystems (Zarta, 2017; Sánchez, 2019). Presently, agricultural activities, especially those industrialized, do not adjust to these objectives because they nearly always privilege obtaining economic profit, which contributes to climate change, soil degradation, environmental pollution and resource scarcity; therefore, it is essential to know the level of sustainability of agroecosystems and their implications in economic, environmental and social terms (Cuadras-Berrelleza *et al*., 2021; Pinedo-Taco *et al*., 2021). To achieve this, there are various evaluation tools, among which one of the most frequently used is the Framework for the Evaluation of Natural Resource Management Incorporating Sustainability Indicators (*Marco para la Evaluación de Sistemas de Manejo de Recursos Naturales Incorporando Indicadores de Sustentabilidad*, MESMIS) (Masera *et al.*, 1999). Having sustainability indicators allows an understanding of the system's functioning and its eventual transformation (Olmos and González, 2013; Arnés and Astier, 2018).

Because of their characteristics, each AES can be sustainable. The sugarcane agroecosystem is among those considered unsustainable, due to the farming practices used for its production, specifically due to the burning that is conducted before the harvest and because of the indiscriminate use of synthetic products (FIRA, 2010; Vilaboa and Barroso, 2013; Salgado, 2015). However, according to INIFAP (2018), it is one of the crops with the greatest economic and social importance for Mexico. Given that it is farmed in 15 states and 227 municipalities, it generates close to 2 million direct and indirect jobs with an economic spill of $30,000 million pesos annually. However, since the so-called Green Revolution was implemented, Mexico has a high dependency on agrochemicals in sugarcane production. The indiscriminate application of pesticides can cause diverse damages to the environment, both to the flora and to the fauna, including the contamination of soils, water tables, and continental and coastal sources of water. However, the cost-benefit analysis of agricultural production generally excludes or minimizes the externalities from the use of pesticides, as well as the negative impacts on society and the environment (Ramírez-Mora *et al.*, 2018).

Likewise, the sugarcane AES not only has dietary and economic importance (as a generator of jobs and currency derived from sugar exports), but it also has essential energetic importance, being responsible for a large percentage of the energy that human beings need for their development. However, the relative delay in scientific research on sugarcane is noticeable, for example, in growth modelling, because there are only two types available for any user (APSIM-Sugar and DSSAT/CANEGRO) compared to other crops of economic importance for developing countries, such as wheat and corn (Marin *et al.*, 2018).

Specifically, in the state of Campeche, Mexico, sugarcane is the most important crop, with a cultivated surface of 18,586 ha and production of 1,003 782 tons, after corn; therefore, 2,389 farmers and their families depend on this activity (INEGI, 2021; SIAP, 2021). This crop, whose genetic potential is still far from being fully used, can be farmed with much more sustainable techniques, both in economic and ecological terms, than those which until today have been considered only in developed countries, whose techniques are based on the intensive use of mineral fertilizers and pesticides. To this end, Campeche has various institutions, including universities and research centers such as the Colegio de Postgraduados, which promote sustainable practices in agricultural activities, such as the use of organic fertilizers, biological control through entomopathogenic fungi, etc.

Because of this, the objective of this research was to understand the degree of sustainability of the sugarcane agroecosystem in the community of Sihochac, which belongs to the municipality of Champotón, Campeche, through the analysis and evaluation of economic, environmental and sociocultural indicators.

MATERIALS AND METHODS

Study area

The study was carried out in the community of Sihochac, in the municipality of Champotón, Campeche, Mexico, between 19°30'01.636" of Latitude North and 90°35'03.661" of longitude West at an altitude of 12 meters above sea level (masl). The climate is Aw_2 (warm sub-humid), with a mean annual temperature of 26 °C and precipitation of 600 to 400 mm (Hernández *et al*., 2018). This community is located within the sugarcane-growing zone of the municipality mentioned, so the sugarcane crop, farmed mainly in Leptosol and Gleysol soils, constitutes the greatest source of income for families in the community (INAFED, 2010; SAGARPA, 2015; INEGI, 2020). The total population of this study zone is 2,756 inhabitants, of which 1,353 are men and 1,403 women; likewise, 1,974 are older than 18 and 432 are 60 or older. On average, they have nine years of education and only 350 of them have finished high school (INEGI, 2020).

Determination of the sample size

The size of the sample was calculated through the finite population formula (Sierra, 1995):

$$\boldsymbol{n = \frac{N \times Z_a^2 \times p \times q}{d^2(N-1) + Z_a^2 \times p \times q}}$$

Where: N= population size= 1,200 farmers; Zα= confidence level= 1.962 (if security is 95%); p= expected proportion= 5%= 0.05; q= probability of failure= 1-p (in this case 1-0.05) = 0.95; d= precision= 5%= 0.05.

The size of the population (N) was based on the information provided by the president of the National Peasant Confederation (*Confederación Nacional Campesina*, CNC, in Spanish) of the municipality of Champotón, Campeche. Based on the equation for the sample size, the number of farmers surveyed was 70.

Elaboration and evaluation of indicators

The methodological framework for the evaluation of the sustainability of the sugarcane agroecosystem was based on the indicators proposed in the MESMIS model (Masera *et al*., 1999), one of the most frequently used in sustainability evaluations in Mexico (Martínez-Castro *et al*., 2016). The information required to achieve the study's objective was obtained through a participatory process, so a semi-structured interview was applied. A poll was carried out through which economic aspects were considered, such as production costs, income, sale prices; environmental aspects such as the use of manure, fertilizers, use of residues; and sociocultural aspects such as sowing season and organization (Table 1). This information was obtained through informal talks with farmers and those in charge of the community, as well as field visits to identify the sugarcane agroecosystems.

We identified critical points related to sustainability attributes (productivity, stability, resilience, reliability, adaptability, equitability, and self-dependence) to which diagnostic criteria were assigned to obtain economic, environmental, and sociocultural indicators for evaluation (Table 1).

Later, critical points related to the attributes of sustainability (productivity, stability, resilience, reliability, adaptability, equity and auto-dependency) were identified, to define key indicators for the evaluation. To measure and monitor these indicators, criteria from the evaluation method proposed by Sarandón (2002) and Sarandón *et al*. (2006) were also used; therefore, each indicator was assigned a quantifiable value in the scale of 0 to 4 (Table 2), where $\leq$ 0 is very unsustainable, $\leq$ 1 unsustainable, $\geq$ 2 barely sustainable, $\geq$ 3 sustainable, $\geq$ 4 very sustainable; this allowed obtaining sub-indicators for better information gathering through a questionnaire with multiple option questions that was applied randomly through the snowball method, regardless of age or sex, as long as the respondents were owners of a surface with sugarcane crop.

Information analysis

Excel was used for the statistical analysis, and sustainability indices were calculated for each dimension (ESI, ASI and SCSI) based on the values obtained, according to Márquez *et al*. (2016). The average of the indices obtained reflected the value of the General Sustainability Index (GenSI) (Table 3).

The indices of each dimension were analyzed and interpreted according to Sarandón *et al*. (2006); to consider each dimension as sustainable, the value of the corresponding index could not be lower than 2, similar to the GenSI of the sugarcane agroecosystem.

Table 1. Attributes of sustainability, critical points and economic, environmental and sociocultural indicators for the evaluation of sustainability.

Attribute	Critical point	Diagnosis criterion	Indicator	Area of evaluation
Productivity	High and low yield Low income	Efficiency	Cost benefit	E
Stability, resilience and reliability	Frequency of damage from pests and transfer of crop burning	Vulnerability	Loss of harvest	E
	Few practices of natural resource conservation	Conservation of resources	Conservation of resources	A
	Diversity of economic activities	Diversity of activities outside the farm	Activities outside the farm	E
	Cultivation of different varieties of the species	Distribution of risk	Varieties sown	A
	Accessibility to credits per year		Access to credits per year	SC
	Low level of satisfaction of basic needs	Quality of life	Satisfaction of the basic needs	SC
	Farmers satisfied with the production system	Permanence	Satisfaction with agriculture implemented	SC
Adaptability	Scarce training support	Capacity for change	Attendance to training workshops or consultancies per yea	SC
Equity	Farmers supported by the sugar plant for productivity	Distribution of backing among farmers	Farmers backed by the sugar plant for productivity	SC
Auto-dependency	Good organization	Organizational structures	Participation in groups	SC
		Social integration	Belonging to social assistance programs	SC
			Relationship with members of the community	SC

Table 2. Sub-indicators and measurement scales of economic, environmental and sociocultural indicators for evaluation (modified from Sarandón, 2002).

Indicator	Variables	Scale	Area of evaluation
A-Cost benefit	A1- Yield ton/ha in the last harvest	(4) More than 81 to 70; (3) From 61 to 80; (2) From 41 to 60; (1) From 21 to 40; (0) Less than 20.	E
	A2- Cost of investment per hectare to prepare the land	(4) Less than $10,000; (3) From $ 10,000 to $19,000; (2) From $20,000 to $29,000; (1) From $30,000 to $39,000; (0) More than $40,000.	E
	A3- Cost per hectare for seed purchase	(4) Less than $2,000; (3) From $2,000 to $2,900; (2) From $3,000 to $3,900; (1) From $4,000 to $4,900; (0) From $5,000 to $5,900.	E
	A4- Cost of weed control	(4) Less than $5,000; (3) From $5,000 to $10,000; (2) From $10,000 to $19,000; (1) From $20,000 to $29,000; (0) More than $30,000.	E
	A5- Cost of fertilizer per ha	(4) Less than $5,000; (3) From $5,000 to $10,000; (2) From $10,000 to $19,000; (1) From $20,000 to $29,000; (0) More than $30,000.	E
	A6- Cost of labor per ha	(4) Less than $5000; (3) From $5,000 to $10,000; (2) From $10,000 to $19,000; (1) From $20,000 to $29,000; (0) More than $30,000.	E

Indicator	Variables	Scale	Area of evaluation
	A7- Total income per hectare	(4) More than $ 64,000; (3) From $42,000 to $63,999; (2) From $32,000 to 41,999; (1) From $16,000 to $31,999; (0) Less than $15,999	E
B-Loss of harvest	B1-Percentage of losses per hectare	(4) From 0 to 9%; (3) From 10 to 29%; (2) From 30 to 49%; (1) From 50 to 69%; (0) More than 70%.	E
A-Conservation of resources	A1- Number of synthetic products used	(4) Zero products; (3) One product; (2) Two products; (1) Three products; (0) Four products or more	A
	A2- Number of organic products used	(4) More than four products; (3) Three products; (2) Two products; (1) One product; (0) Zero products	A
	A3- Techniques of use of agricultural and livestock residues	(4) Vermicompost; (3) Compost; (2) Bioles; (1) Integration to the soil; (0) Burning them	A
	A4- Hectares destined to conservation	(4) More than 2.1 ha; (3) From 1.1 to 2.00 ha; (2) From 0.51 to 1.00; (1) From 0.1 to 0.5 ha; (0) Does not have any conservation area	A
C-Activities outside the farm	C1-Activities outside the plot	(4) More than four activities; (3) Three activities; (2) Two activities; (1) One activity; (0) Activities	E
B-Varieties sown	B1- Number of varieties sown	(4) More than four varieties; (3) Four varieties; (2) Three varieties; (1) Two varieties; (0) One variety	A
A-Access to credits per year	A1- Number of credits received per year	(4) More than three; (3) Three; (2) Two; (1) One; (0) None	SC
B-Satisfaction of the basic needs	B1- Condition of the household	(4) Their own; (3) Borrowed from work; (2) Leased; (1) Still paying it; (0) Lives in a family member's or friend's house	SC
	B2- Employment situation	(4) Six days; (3) Four days; (2) Three days; (1) Two days; (0) One day	SC
	B3- Access to education	(4) Access to higher education and/or training courses; (3) Access to secondary and high school; (2) Access to primary and secondary school; (1) Access to primary and secondary school with restrictions; (0) Without access to education	SC
	B4-Access to health	(4) Private; (3) ISSSTE; (2) IMSS; (1) Community health center; (0) Without access to health services	SC
	B5- Access to public services	(4) Complete water, electricity, telephone and internet facilities; (3) Electricity, water and telephone; (2) Electricity and well water; (1) Without electricity and water from a nearby well; (0) Without electricity and without a nearby source of water	SC
	B6-Presence of serious disease in the family	(4) None; (3) One disease; (2) Two diseases; (1) Three diseases; (0) More than three diseases	SC
C-Satisfaction with agriculture implemented	C1- Satisfaction with agriculture implemented	(4) Is very happy with the activity. Would not do anything else, even if it meant more income; (3) Is happy, but did much better before; (2) Is not completely satisfied. Stays because it is the only thing they know how to do; (1) Unsatisfied with this way of life. Yearns to live in the city and do something else; (0) Is disillusioned with the life they lead, would not do it anymore. Is waiting for an opportunity to leave agriculture	SC
	C2- Level of wishing to continue in agriculture	(4) Too much; (3) A lot; (2) A little; (1) Almost nothing; (0) Nothing	SC

Indicator	Variables	Scale	Area of evaluation
	C3- Wish of heir to continue in agriculture	(4) Too much; (3) A lot; (2) A little; (1) Almost nothing; (0) Nothing	SC
D. Attendance to training workshops or consultancies per year	D1-Number of times of training or consultancy per year	(4) More than three; (3) Three; (2) Two; (1) One; (0) None	SC
E-Farmers backed by the sugar plant for productivity	E1-Number of farmers backed by the sugar plant	(4) 100%; (3) 75%; (2) 50 %; (1) 25%; (0) 15%	SC
F- Participation in groups	F1-Time of permanence in farmers' groups	(4) More than four years; (3) Three years; (2) Two years; (1) One year; (0) Has never belonged to one	SC
G. Belonging to social assistance programs	G1- Number of social programs to which they belong	(4) More than three; (3) Three; (2) Two; (1) One; (0) None	SC
H. Relationship with members of the community	H1- Relationship with community members	(4) Very good; (3) Good; (2) Average; (1) Bad; (0) Very bad	SC

Table 3. Sustainability indices formulas.

Indice	Formula
ISE	$= \frac{(A1+A2+A3+A4+A5+A6+A7)/7+B+C)}{3}$
ISA	$= \frac{(A1+A2+A3+A4)/4+B)}{2}$
ISSC	$= \frac{(A+(B1+B2+B3+B4+B5+B6)/6+(C1+C2+C3)/3+D+E+F+G+H)}{8}$
ISGen	$= IA + IE + ISSC/3$

RESULTS AND DISCUSSION

The farmers surveyed belong to five sugarcane-growing groups (Benito Juárez, Cañeros de Sihochac, Nueva Manera, Roque Espinoza, and Unión y Libertad); the largest group was Cañeros de Sihochac with 28 people and the smallest was Unión y Libertad with five people. Likewise, statistical differences were found regarding the "age" variable in some groups of farmers; the youngest producer was 45 years old, belonging to the Nueva Manera group, and the oldest was 60 years old, belonging to the Unión y Libertad group. However, for the "education" variable, no statistical differences were found, which is why this datum between the groups was very similar (nine years on average). The highest percentage of the survey respondents are of peasant occupation, then homemakers and a minority also perform some other activity (Table 4).

On the other hand, the sugarcane agroecosystem is a monocrop managed by the family and with paid labor, through contract agriculture with the sugar mill "La Joya" (Figure 1); however, for this, it is necessary for the land owner to be affiliated to one of the sugarcane-growing groups mentioned before, which are coordinated by sugar mill this is a requirement to trade the product and for the supply of inputs and implements for sowing and harvest. Although sugarcane growing is the main activity of this community, the low production many times means insufficient income for the basic needs of farmers and their families, a situation that forces them to search for extra activities in farming or services such as corn sowing, beekeeping, bricklaying, nursing, maquila outsourcing, sewing, and being employees in the private sector. This need to diversify activities is because of the high investment costs and the low income obtained from selling the product in the productive systems as a consequence of the impact of pests, diseases and the transfer of crop burning in the harvest stage. Therefore, the profits obtained from being employed outside the production unit are an economic complement for basic needs (Ávila *et al*., 2016). However, it is important to mention that despite the low income from sugarcane production during some seasons, this agroecosystem presents positive aspects that lead to the permanence of the activity; for example, the backing for welfare production, provided annually to all the sugarcane farmers by the government, in addition to being organized through community sugarcane-growing groups which ensures a permanent economic pension when they retire from this activity (Figure 1).

Economic sustainability

Of the economic indicators evaluated, the indicator B-losses in the crop reached the highest score (2.87) given that only 6% of the farmers indicated having this problem in more than 70% of the surface sown; however, the value of this indicator barely exceeds the threshold value, because part of the losses of product are due to damages from fire transfer when burning during the harvest, or from the impact of the most important pests in the region, such as spotted fly or spittlebug and the borer, situation that generates a reduction in production and productivity, as well as monetary income. In this sense, Concepción *et al*. (2015) agrees with the results when they mention that, in addition to these events, sugarcane production is affected by the inadequate composition of strains, the low access to areas of certified seed, and the scarce knowledge that farmers have about sugarcane plant science. Thus, it was seen that sugarcane agroecosystems were barely sustainable both in the indicator A = cost-benefit and in the indicator B-losses, because despite attaining significant yields compared to the national mean (75.4 t) (Reyes-Hernández *et al*., 2022), the net annual incomes from production sale are limited (approximately $70,000.00), amount that is

Table 4. Socioeconomic variables by sugarcane groups of Sihochac, Champotón, Campeche, México.

Groups	n	Age	Years of Schooling	Occupation		
				Housewife	Peasant	Employee
Benito Juárez	11	49.91 AB*	8.55 A	9.09	90.91	0
Cañeros de Sihochac	28	51.11 AB*	9.36 A	25	64.29	10.71
Nueva Manera	7	45.14 B*	9.57 A	14.29	71.43	14.29
Roque Espinoza	19	50.47 AB*	8.53 A	15.79	68.42	15.79
Unión y libertad	5	60.60 A*	9.20 A	60	40	0
Total	70	50.83*	9.01 A	21.43	68.57	10

* Different letters mean statistical differences between the groups.

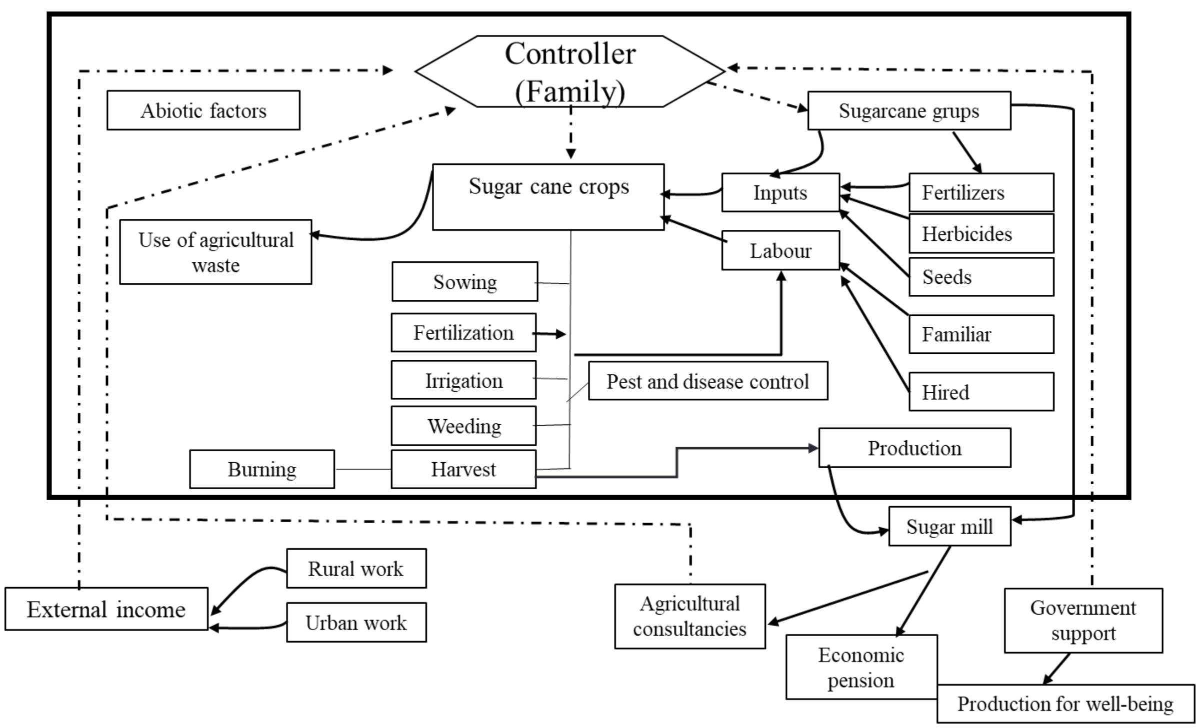

Figure 1. Model of the sugarcane agroecosystem in the community of Sihochac, Champotón, Campeche, México.

barely enough to cover the production costs, without obtaining net profits. In this regard, González-Flores *et al*. (2020) and Espinola *et al*. (2017) argue that when economic resources are insufficient for the family's sustenance, farmers are forced to perform other economic activities to complement them (Table 5).

Environmental sustainability

The environmental indicators reached a sustainability index of 0.57 (Table 6), so it is not sustainable. Among the indicators evaluated, A-Resource conservation and B-Varieties sown, had values < 2, with few varieties and low resource conservation, because 74% of the sugarcane growers in the community do not sow more than three varieties of sugarcane and apply more than four chemical products of synthetic origin on the crop, among which Glyphosate and Paraquat stand out. According to Rasgado *et al*. (2019), if soil conservation practices are implemented consecutively, its quality is improved, increases the diversity of microorganisms and at the same time the environmental sustainability of productive ecosystems is favored.

The low values obtained in indicators A-Resource conservation and B-Varieties sown in the agroecosystem may be because the AES is managed conventionally; for example, the use of high doses of insecticides, herbicides and fertilizers, a similar phenomenon found by Ramírez-Mora *et al*. (2019) in La Antigua, Veracruz, where 100% of the interview respondents apply this type of products, several of which are not approved for their use in countries of the European Union. According to these authors, some of them are carbofuran, carbosulfan, monocrotophos, ametryn, 2,4-D, MSMA, paraquat, diuron and picloram, which have been associated with symptoms such as headaches, nausea, dizziness, loss of consciousness and various respiratory symptoms, and the presence of carcinogenesis, endocrine disruption, asthma, among other effects in the short, medium and long term.

Furthermore, the low value obtained in the environmental aspect indicates negative effects and impacts on the agroecosystem. According to Moreno (2022), damage to water, soil and air, in addition to the loss of biological diversity, causes changes that translate into dangers and risks of various kinds and importance for humanity and other living beings, such as damage to health through the appearance of infectious diseases, food insecurity, among others. To counteract some effects of soil contamination, there are various practices such as bioremediation, using humic substances from vermicompost (Ojeda-Morales *et al*., 2023) and even using the same waste from the mills such as bagasse and sugar cane filter cake applied as amendments and texturizers, which have been shown to have the ability to restore soils contaminated with hydrocarbons (García-Torres *et al*., 2011).

Table 5. Economic indicators and variables of the sugarcane AES of Sihochac, Champotón, Campeche, México, when the ESI reached a value > 2, the variable is sustainable.

Indicator	Variables	Value	Final value
A- Cost benefit	A1- Yield ton/ha in the last harvest	2.50	2.69
	A2- Cost of investment per hectare to prepare the land	3.25	
	A3- Cost per hectare for seed purchase	1.97	
	A4- Cost of weed control	3.54	
	A5- Cost of fertilizer per ha	3.14	
	A6- Cost of labor per ha	3.20	
	A7- Total income per hectare	1.18	
B- Crop losses	B1- Percentage of losses per hectare	2.87	2.87
C-	Activities outside the farm	0.88	0.89
ISE			2.14

Table 6. Environmental indicators and variables of the sugarcane AES of Sihochac, Champotón, Campeche, México.

Indicator	Variables	Value	Final value
A= Conservation of resources	A1- Number of synthetic products used	0.3	0.25
	A2- Number of organic products used	0.17	
	A3- Techniques of use of agricultural and livestock residues	0.17	
	A4- Hectares destined to conservation	0.38	
B= Varieties sown	B1- Number of varieties sown	0.90	0.90
ISA		0.57	

Giraldo and Valencia (2010) mention that an agroecological production system is more environmentally sustainable than a conventional one, since the conservation of natural resources, the preservation of biodiversity, and the use of inputs of biological origin for pest and disease control are emphasized, and a man-nature interaction is established that is not mediated by obtaining profit, but by the respect for nature's cycles, rhythms and times, configuring a biodiverse landscape rich in singularities.

Sociocultural sustainability

The lowest value was for indicator D-Attendance to training workshops, because barely 5% of the farmers receive training for the agricultural activity at least three times per year. Meanwhile, the value obtained both of E and F could be because each producer is affiliated to a sugarcane-growing group, which has its representation in the La Joya sugar mill for the sale of their product, and for receiving the backing of inputs during the entire productive process; however, they do not belong to any other group or government or non-government organization. On the other hand, the value of D would have an explanation in the few courses or training programs that they receive for crop production, with these being scarcely one course or no course per year; however, some of the farmers show interest in receiving them, although there are others that are not interested in this support. Not receiving courses or training is reflected in crop management from the point of view of plant health, the excessive use of pesticides as the sole tool for pest control, not attending adequately to the multiple tasks that this crop demands, and not applying sustainable practices, including Good Agricultural Practices (GAP). In this regard, Vallejo *et al*. (2016) point out that for many farmers these activities are of great importance and that they would be willing to participate in them, because this would allow to solve questions about technical aspects of the crop, innovating and acquiring new knowledge that could lead them to make their productivity more efficient. Likewise, according to Cuevas *et al*. (2012), in Mexico training to improve agricultural and livestock production is offered by technicians (70.8%), farmers (17.7%), academic or research institutions (2.8%), and offices (1.5%); however, this training is many times focused on the increase in productivity without considering aspects of conservation or promotion of sustainability. Therefore, the importance of training for agricultural production is evident and more so in environmental subjects, as one of the alternatives for the recognition of the value of conservation of natural resources in the planet. The E-Farmers indicator supported by the sugar mill for productivity, was the one that showed highest sociocultural sustainability value, followed by F-Participation in groups (Table 7).

On the other hand, a low value was obtained for A-Access to credits per year, since 48% of the farmers mentioned they do not have access to one of these, while another 48% mentioned having the possibility of gaining access to only one. However, there is an annual government support, through the program Production for Welfare ($7,000.00), which is barely enough to purchase some inputs used in the crop. According to Figueroa *et al*. (2015), the innovations that should be implemented in the sugarcane production systems in Mexico urgently need support to improve human capacities that tend to empower farmers and field workers, technicians, and decision-makers, so the organization of farmers is fundamental to improve the efficiency and competitiveness of the sugarcane production.

On the other hand, the variables that makeup indicator B-Satisfaction of basic needs, showed considerable values of sustainability, which indicate that most of the sugarcane farmers have good housing, employment, access to education, health services and public services, which agrees with the idea by Boltvinik (1990), by emphasizing that all people have the right to satisfy these needs just by existing. In this sense, the sugarcane farmers from Sihochac mentioned being satisfied with this agricultural activity, and they also revealed having a good working relationship with all the members of the sugarcane-growing community, that's the reason why this indicator reached a value of 3.07; therefore, 25 of them are under the mean and the remaining 45 are above it.

General Sustainability Index

The sugarcane agroecosystem presented a General Sustainability Index (GenSI) of 1.68 (Table 8), according to the criteria established by Sarandón (2002), it is not sustainable.

In particular, the environmental component is the least sustainable compared to the economic and sociocultural ones because the value of the sustainability indices of both is higher than the threshold, although the economic one is higher (Figure 2). The values obtained in the sustainability indicators studied are largely because the sugarcane agroecosystem is managed almost exclusively with external energy, especially herbicides and fertilizers that are provided by the La Joya sugar mill. However, these inputs are removed from the final payment received by the producers, which means a reduction up to 60% in profits; this agrees with what Ribón *et al.* (2003) found in the sugarcane area of the Santa Rosalía sugar mill in Tabasco, Mexico. Likewise, Naranjo *et al.* (2006) evaluated this agroecosystem three years later and reached the same conclusion about its low economic sustainability.

Table 7. Sociocultural indicators and variables of the sugarcane AES of Sihochac, Champotón, Campeche, México.

Indicator	Variables	Value	Final value
A-Access to credits per year	A1- Number of credits received per year	0.57	0.57
B-Satisfaction of the basic needs	B1- Condition of household	3.07	3.04
	B2- Situation of employment	3.78	
	B3- Access to education	2.77	
	B4- Access to health	2.07	
	B5- Access to public services	3.04	
	B6- Presence of serious disease in the family	3.51	
C-Satisfaction with the agriculture implemented	C1- Satisfaction with the agriculture implemented	3.52	2.94
	C2- Level of wish to continue in agriculture	3.00	
	C3- Wish of heir to continue in agriculture	2.32	
D. Attendance to training workshops or consultancies per year	D1-Number of times of training or consultancy per year	0.47	0.47
E-Farmers backed by the sugar plant for productivity	E1-Number of farmers backed by the sugar plant	4.00	4
F- Participation in groups	F- Participation in groups	3.94	3.94
G. Belonging to social welfare programs	G1- Number of social programs to which they belong	0.55	0.55
H. Relationship with members of the community	H1- Relationship with members of the community	3.07	3.07
SCSI			2.32

Table 8. General Sustainability of the AES sugar cane of Sihochac, Champotón, Campeche, México.

Economic sustainability index ISE A+B+C/3	**Environmental sustainability index ISA** A+B/2	**Index of sociocultural sustainability ISC** A+B+C+D+E+F+G+H/8	**General Sustainability Index ISGen** ISE+ISA+ISSC/3
2.14	0.57	2.32	1.68

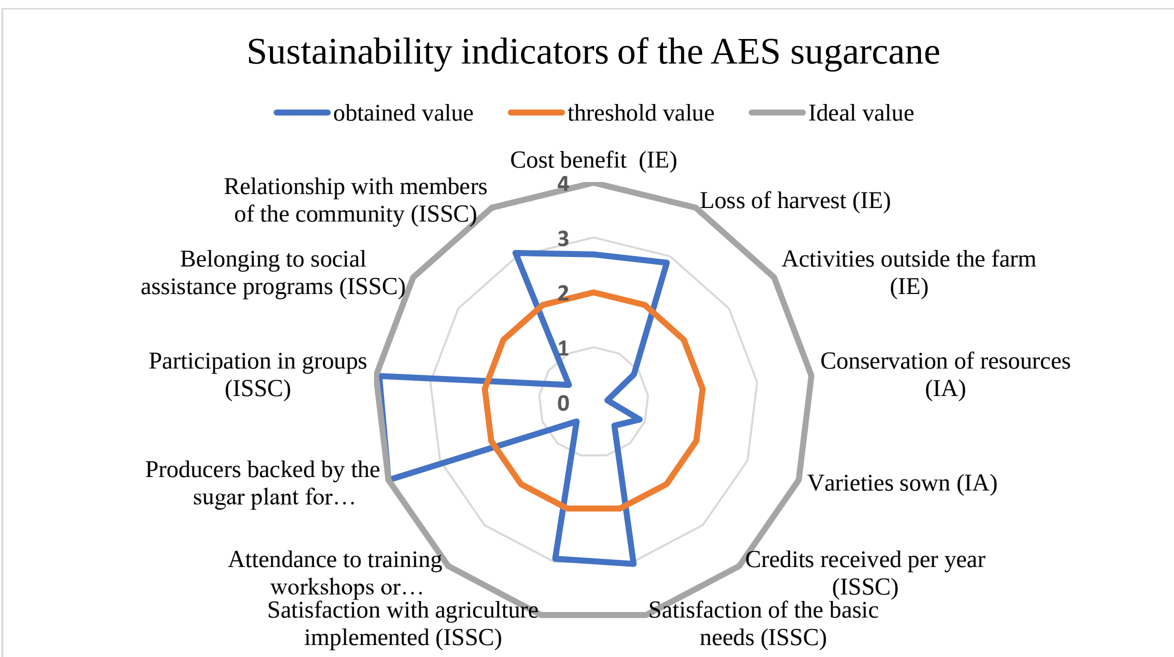

Figure 2. Representation of sustainability indicators of the AES sugar cane of Sihochac, Champotón, Campeche, México. IE= Economic indicator, (IA)= Environmental indicator and (ISSC)= Sociocultural indicator.

For the environmental dimension, Naranjo *et al*. (2006) mentioned that part of the situation is because of the sugarcane plantation burning, which prevents the reincorporation of organic matter to the soil, degrading its physical, chemical and biological properties. It also generates air pollution and emits greenhouse gases (Fragoso-Servón *et al*., 2023). Likewise, Pérez and Galindo (2022) add the use of agricultural machinery, and the traffic of heavy vehicles used during the harvest, which generate a large quantity and diversity of air pollutants, as other of the main factors that distance the sugarcane agroecosystem from being environmentally sustainable. At the same time, these authors point out that all these factors allow us to affirm that the continuity of the sector is at risk, even without considering climate change scenarios, the growing tendency to reduce per capita sugar consumption, and the emergence of new highly competitive producing countries.

Like the sugarcane agroecosystem evaluated in this study, low values of sustainability were found in other types of AES, for example, in Persian lime AES in Martínez de la Torre, Veracruz, Mexico Franco-Valderrama *et al*. (2022) reported the lowest values of sustainability for the economic indicators, compared with environmental and social indicators. Chamorro and Sarandón (2021) point out that the diverse soil conditions and the technology used in each territory have important effects on sustainability, influencing different components and/or common goods for example impacts on the use of water and soil nutrients.

As complement, regarding the biodiversity present in the AES, it is interesting to highlight that Lang-Ovalle *et al*. (2011) did not find statistically significant differences between the diversity and the abundance of soil macrofauna such as ants, earthworms, termites, myriapods, and annelids when comparing a sugarcane AES with a mango AES, because it was tolerant to the management conditions in the sugarcane AES.

The GenSI obtained in this evaluation (1.68) is nearly similar (1.86) to the one reported by Jácome *et al*. (2020) when they evaluated the sustainability management of natural resources in the Yungañán River micro-basin, in the Ecuadorian Andes, for various agricultural crops.

In addition to this, Salgado *et al*. (2015) pointed out that an agricultural activity is considered sustainable when it is socially acceptable, technically feasible, financially profitable, and ecologically viable; therefore, they propose that in order to improve the sustainability of the sugarcane AES, some activities must be carried out, such as reducing burns, modifying the current cultivation system, and promoting the diversification of sugarcane agroindustry to give a better use to the residues of the agricultural and industry process of sugarcane, such as compost elaboration.

CONCLUSIONS

The sugarcane AES in the locality of Sihochac is not sustainable because it presented a GenSI value of 1.68. When the economic, environmental and sociocultural indicators (2.14, 0.57 and 2.32, respectively) were compared, it was found that the latter had the highest value, although it barely exceeds the threshold to be considered as a sustainable agroecosystem in this dimension.

However, the environmental indicators of the sugarcane agroecosystem studied are the most worrying, not only due to the importance of this economic activity, but also because management practices are highly dependent on external inputs that contaminate water, soil and air, causing loss of biodiversity and deterioration of the surrounding ecosystems, which in turn affects the quality of life of human beings and other organisms with which the space is shared. Some environmental practices that could be adopted are the use of varieties that are more resistant to pests and diseases which require fewer synthetic products; using organic fertilizers like vermicompost or compost elaborated with agricultural residues, even those produced in the sugar mill; using entomopathogenic fungi to combat the spotted fly, borers, billbugs, etc.

In the sociocultural aspect, social relationships must be promoted through farmer’s organizations, as well as fairer and more solidary backing both for sugarcane farmers and for representatives of the groups.

Economically, it is essential to establish fairer and more competitive prices in this sector so that those who depend on this activity can increase their income and attain better living conditions.

Acknowledgment
To the SECIHTI and Colegio de Postgraduados Campus Campeche for allowing this research to be carried out.

Funding. The authors of the article declare no support was received for this study.

Conflict of interest. The authors declare that there is not conflict of interest.

Compliance with ethical standards. Authorization was obtained from the corresponding authorities in the study community. The producers also gave their informed consent to conduct the survey.

Data availability. Data are available with the corresponding author (V. Rosales-Martínez: vrosales@colpos.mx) upon reasonable request.

Author contribution statement (CRediT). **L.L. Candelario-Rosales** – Methodology, investigation, writing; **C.H. Ávila-Bello** − Methodology, investigation, review & editing; **C. Flota-Bañuelos** - Investigation, Data curation, writing an original draft; **S. Fraire-Cordero** – Investigation, Data curation, writing an original draft; **V. Rosales-Martínez** – Supervision, formal analysis, conceptualization, review & editing.

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