The sustainability of sugarcane production: A systematic review of sustainability indicators

Gabriel Chico Viegas*, Ana Marta-Costa**,
Rui Fragoso***, Edgar Cambaza*

DOI: 10.30682/nm2404h
JEL codes: Q01, Q13

Abstract

This review aims to identify indicators to assess the sustainability of sugarcane production. Preferred Reporting Items for Systematic Reviews and Meta-analyses reviewed 44 eligible articles from Scopus and Web of Science databases. The results show that only 34% of the identified studies focus on the three sustainability dimensions: environmental, economic and social. The social dimension continues to be under-studied. From the 119 indicators identified, 16 common indicators used to assess the sustainability of sugarcane were identified, and the analysis of frequency shows that the most commonly suggested indicators were Greenhouse gas emissions, Water use, Water quality, Employment generation, and Initiatives to promote the Local community's welfare, Profit, and Distance to sugar mills. Further, research combining the three dimensions of sustainability and those that separately evaluate the sustainability of sugarcane in the production stage on the field and the factory is recommended.

Keywords*: Sustainability indicators, Sustainability dimensions, Sugarcane production systems, PRISMA framework.*

1. Introduction

Sugarcane plantations are one of the world's fastest-growing agricultural systems, contributing around 21% of global crop production between 2000 and 2020 and generating significant revenue for many nations. Although sugarcane production has positively impacted the economy, it has led to increased greenhouse gas emissions, biodiversity loss, soil erosion, nutrient loss, soil pollution, expropriation of land and resources, displacement of local populations, and land tenure disputes (Hall *et al*., 2017; Souto *et al*., 2024). In this context, assessing sugarcane production sustainability is crucial for agribusiness survival and market competitiveness, ensuring a sustainable future through environmentally, economically, and socially responsible farming practices (TraceX Technologies, 2023).

They are the operational representation of a system's attributes and allow for measuring and monitoring changes that are relevant to human and environmental well-being (Gamboa *et al*., 2016; Waas *et al*., 2014).

Although numerous approaches and indicators have been created and examined to assess the sustainability of agricultural systems over the years, finding a consensus model for efficient

* ISCED Open University, Beira, Sofala, Mozambique.
** University of Trás-os-Montes and Alto Douro, Centre for Transdisciplinary Development Studies (CETRAD), Vila Real, Portugal.
*** University of Évora, Center for Advanced Studies in Management and Economics (CEFAGE), Évora, Portugal.
Corresponding author: gabrielviegas19@gmail.com

assessment of the sustainability of sugarcane production has proven challenging (Latruffe *et al*., 2016; Rasmussen *et al*., 2017). Therefore, the systematic literature review will be the first to combine different indicators to assess the sustainability of sugarcane, creating groups of indicators that can be used as a reference to assess the sustainability of this crop in the future. Combining indicators from the main pillars of sustainability can help us understand how sugarcane production systems affect the environment, economy, and society. The results will guide sugarcane farmers, academics, and policymakers on which indicators to prioritize in production, strategies, and policy.

The review has six parts: (1) Introduction, which contextualizes the study; (2) Literature Review, which discusses sustainability and sustainability indicators; (3) Methodology, which describes the article's construction; (4) Results, which presents the findings; (5) Discussion, which analyzes and contrasts the findings to other studies with a similar research focus; and (6) Conclusion, which answers the objectives and identifies the article's contribution, limitations, and suggestions for future studies.

2. Literature review

2.1. *Sustainable Development and Sustainability*

According to the World Commission on Environment and Development (1987), sustainable development is economically viable, environmentally sound, and socially acceptable development that meets current demands without compromising future needs. However, Pham and Smith (2014) argue that this concept is ambiguous and open to interpretation. Although sustainable development is often used as a synonym for sustainability, they are two different concepts with different meanings. Cruz *et al*. (2018) add that sustainability is the period that a system can maintain itself through a set of management strategies, while Garcia-Bustamante *et al*. (2018) emphasize that sustainability is characteristic of dynamic systems that allow them to keep themselves through time with no discernible endpoint. In summary, sustainability incorporates environmental, economic, and social factors, whereas sustainable development improves economic well-being and quality of life over time without compromising future generations' demands. Ensuring sustainability in different activity systems is the way to achieve sustainable development, which has become a global imperative in recent years (Depetris-Chauvin *et al*., 2023).

In the context of agricultural systems, different authors have deduced the application of sustainability to balance the environmental, economic and social dimensions (Cruz *et al*., 2018; Latruffe *et al*., 2016; Marta-Costa *et al*., 2022; Mokrani *et al*., 2022). Corvo *et al*. (2021) refer to the environmental dimension as focusing on the environmentally sustainable behavior of human activities. Karvonen *et al*. (2017) associate the economic dimension with how agricultural systems improve people's quality of life. Unfortunately, receiving less attention than other dimensions (Massuça *et al*., 2023), Janker and Mann (2020) examine the social dimension, focusing on how agricultural systems influenced by environmental and economic factors contribute to human well-being and social justice.

According to Gayatri *et al*. (2016), focusing on just one dimension of sustainability to the detriment of others can be risky. The same authors emphasize that agricultural production systems cannot be sustainable if they cannot produce enough food or pay farmers sufficiently, even if they maintain environmental quality. Similarly, high-productivity agricultural systems that use more inputs to offset yields or cause environmental damage are not sustainable.

Therefore, it is essential to combine the three dimensions to obtain results that truly reflect the genuine concept of sustainability.

Growing demand for sugar and biofuels has led to increased sugarcane cultivation, raising a myriad of negative impacts on sugarcane production. Garcia-Bustamante *et al*. (2018) identified soil degradation, high water consumption, land use change, atmospheric pollution, inequity in the rural sector, low salaries, and even laborer exploitation as some of the challenges of sugarcane production. Sustainability assessment plays a crucial role in assessing sugarcane pro-

duction's environmental, social, and economic impacts and identifying areas for improvement.

2.2. *Methodologies for assessing sustainability in agriculture*

According to Cruz *et al*. (2018), two main approaches are used to assess sustainability in agriculture, the "bottom-up" and "top-down". The first approach consists of the joint selection of sustainable development indicators and subsequent construction of the global framework in a participatory manner. The "bottom-up" approach is inclusive and can obtain better results by incorporating stakeholders in framework design. On the other hand, the "top-down" approach begins by defining the global sustainability assessment structure, which is further disaggregated into a set of indicators.

Methodologies such as Life Cycle Assessment (LCA), Sustainability Assessment Frameworks (SAFs), and Multi-Criteria Analysis (MCA) have been developed to assess agricultural sustainability (Lacovidou & Voulvoulis, 2018). LCA has gained wider acceptance and is used by most professionals worldwide (Kralisch *et al*., 2015). It quantifies the environmental impacts of sugarcane production throughout its life cycle, from cultivation to processing and consumption (Silalertruksa *et al*., 2017).

For the sugar sector, sustainability assessment has been carried out mainly for sugarcane biorefineries with the integration of sugar, ethanol and the production of by-products. Duarte *et al*. (2013) and Silalertruksa *et al*. (2017) used LCA to assess the environmental footprints of sugarcane ethanol production in Brazil and Thailand, and they identified greenhouse gas emissions, water use, and land use changes as having significant environmental impacts on sugarcane production. Coutinho *et al*. (2017) used a participatory SAF to assess the sustainability of sugarcane expansion in Brazil, involving sugarcane producers, government officials, and environmental organizations, and identify and prioritize sustainability indicators.

Gnansounou *et al*. (2017) employed MCA to assess the sustainability of selected sugarcane biorefinery-centered systems in Brazil, considering environmental, social and economic criteria and comparing their sustainability performance. Based on the same dimensions, Turetta *et al*. (2017) developed a framework to assess the sustainability of the sugarcane sector in Brazil.

In the expectation of improving the sustainability assessment process, the composite sustainability index has been developed for sugar farming through an Analytic Hierarchy Process (AHP) and available ecological, technological and socio-economic data (Aguilar-Rivera, 2019). With the global pressure and appeal for sustainability in all activities, constructing more inclusive, transparent and replicable evaluation methods to assess sustainability became necessary. The SustenAgro Support System, developed by Embrapa in Brazil, has been used to analyze the impacts of different management practices on the sustainability of sugarcane production. It is based on a set of indicators and criteria that cover the three dimensions of sustainability that evaluate and compare systems individually (De Jesus *et al*., 2019). Besides being a current method, SustenAgro was developed by sugarcane experts, includes the three dimensions of sustainability, and can be applied to individual production units for precise, easy-to-interpret results.

However, for sustainability to be assessed, the corresponding indicators must be available (Prasara-A & Gheewala, 2021; Prasara-A *et al*., 2019). According to Cruz *et al*. (2018), sustainability indicators are tools that can evaluate the effects of management changes. They can be used to monitor the trends of a particular condition and help identify challenges that may require additional resources (De Jesus *et al*., 2019). They can also compare sustainability performances between farms, regions and countries. The indicators must satisfy specific requirements, which Shukor and Ng (2022) summarize as follows: (i) be comparable; (ii) show the true nature of the process or function they represent; (iii) be understandable, more reliable and accessible; (iv) be able to build the same criteria and compare them using time series and units; (v) be obtained on a regular enough basis of time to guarantee that the firms take occasional action; and (vi) be understandable for the user and match the user's information needs.

In agriculture, methods such as Delphi, *Indicateurs de Durabilité des Exploitations Agricoles* (Agricultural Sustainability Indicators, IDEA), *Marco para la Evaluación de Sistemas de Manejo incorporando Indicadores de Sustentabilidad* (Management Systems Assessment Framework Incorporating Sustainability Indicators, MESMIS), Monitoring Tool for Integrated Farm Sustainability (MOTIFS), Response-Inducing Sustainability Evaluation (RISE), or Sustainability Assessment of Farming and the Environment Framework (SAFE) have been developed to evaluate sustainability in farming using composite indicators of agricultural sustainability.

The practicality in the procedures and guarantee of the inclusion of the participants of the study area in the process of building, selecting, and validating the indicators has become Delphi well adapted in agriculture (Naisola-Ruiter, 2022; Zhao *et al*., 2023). Its main features are its anonymity and the ability to reduce the influence of one expert to another, contributing to the objectivity of the results (Bélanger *et al*., 2012; Cruz *et al*., 2018).

Sustainability indicators are grouped into economic, environmental, and social (Gani *et al*., 2021), and depending on these aspects, there are different indicators for assessing sustainability in sugarcane systems. According to Garcia-Bustamante *et al*. (2018), Aguilar-Rivera (2022) and Joglekar *et al*. (2022), some examples of indicators are Greenhouse gas emissions, Water use, Biodiversity and Workers' rights.

There are some initiatives to advance the development and application of a universal set of indicators for sugarcane, such as the Bonsucro Production Standard, Bioindicators for the Sustainability of the Sugar Agro-Industry and the Sustainable Sugarcane Initiative (Aguilar-Rivera, 2019). However, these indicators are not universally applicable across contexts and scales (Sawaengsak *et al*., 2019), due to the local conditions, such as soil, climate, social development and others (Aguilar-Rivera, 2022), needing to continually carry out research in different realities to identify common indicators specific to each context.

3. Methodology

The systematic review comprised identifying and selecting publications for analysis using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flowchart (see Figure 1). PRISMA is a framework that guarantees that systematic review reports are more transparent, clear and comprehensive (Li *et al*., 2020). Credible Scopus and Web of Science databases were used in selecting the publications, which have comprehensive global and regional coverage of scientific journals, conference proceedings and books such as pointed out by Baas *et al*. (2020) and Birkle *et al*. (2020). These databases ensure that the highest quality data are indexed through rigorous content selection and re-evaluation by an independent Content Selection and Advisory Board.

Forty-four (44) articles containing the keywords "sugarcane" and "sustainability" in their titles, published between 2013 to 2022, and written in English, Portuguese, and Spanish, were identified using the mentioned databases. The past ten years were selected because important sustainability and climate change events like the Paris Agreement, the UN Sustainable Development Summit, COP26, and COP27, whose decisions impacted agricultural activities, have been highlighted. The inclusion criteria for the systematic review were studies that focused on sugarcane, addressed sugarcane sustainability, and provided the full text of the article. In addition to these criteria, for discussion and achievement of the study objectives, articles that identified or mentioned sustainability indicators received more attention. Documents such as books, book chapters, reviews and conference papers were excluded from the analysis. These items are excluded because books and book chapters are not primary sources and conference articles are not peer-reviewed. The search of articles was open to all subject areas and the data was extracted on July 18, 2023.

To identify the common indicators, the authors followed the adapted approach from Nadaraja *et al*. (2021), which is considered a common indicator - identified in at least two studies. However, it should be noted that this approach can lead to a false impression of the high frequency of an indi-

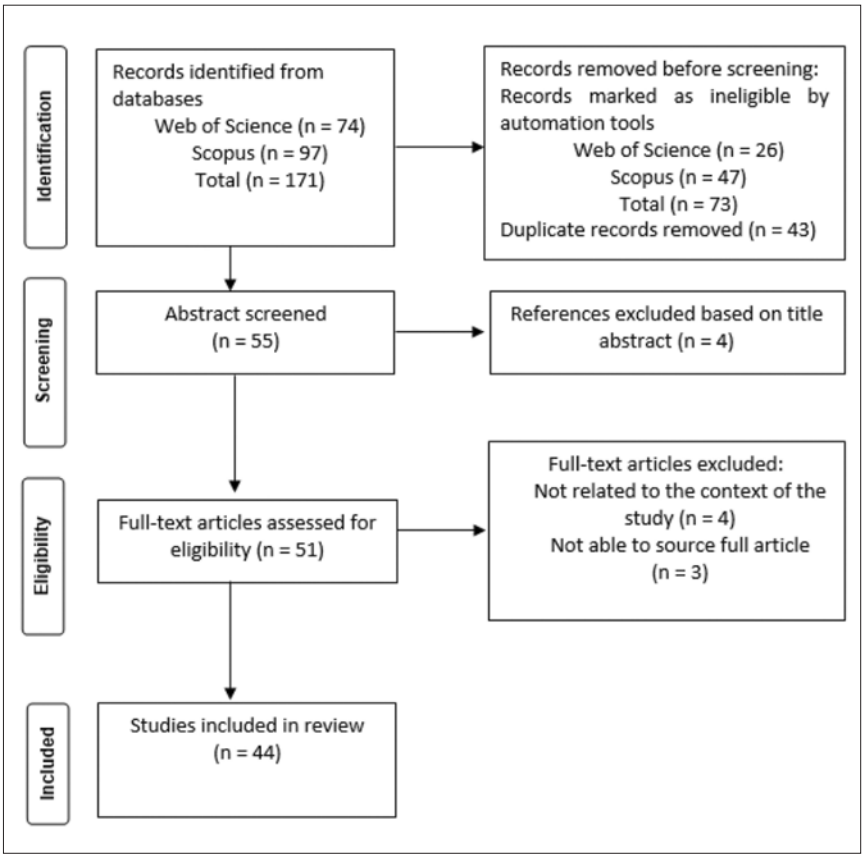


Figure 1 - Outline of the study selection flow diagram.

cator (common and very relevant) because it uses as a reference the number of studies where the indicator is present and not the number of times an indicator has been quoted/researched by different authors. Thus, this situation opens space for situations where the same indicator is present in other studies of the same author. To address this limitation, the present review included indicators indicated in at least two studies by different authors. However, indicators that were frequent in studies by the same author were also included because it is believed that their continued presence in the studies, although these are from the same authors, shows the indicator's relevance.

Information about the dimensions of sustainability addressed in each article and the sustainability indicators identified was extracted and evaluated from the selected articles. Finally, the common indicators used in assessing sugarcane sustainability were analyzed by calculating their frequency in the sample.

4. Results

4.1. *Characterization of the selected database*

The year 2022 had the most publications (10) about the sustainability of sugarcane production out of the 44 total articles reviewed, with 2018 coming in second with seven publications. The least number of publications, two (2), were recorded in 2013 and 2015 (see Figure 2). The increased trend in the number of publications reflects the concern of the government, researchers, and society about sustainable development.

Brazil, the world's largest sugarcane producer, has been the leading country where published studies were conducted, accounting for 41% (see Figure 3). Following Brazil, Thailand and India contributed 18% and 14% of all publications, respectively. The remaining studies were conducted in Mexico, China, Colombia, Cuba, Ecuador, Indonesia, Iran, Jamaica, Portugal, and South Africa.

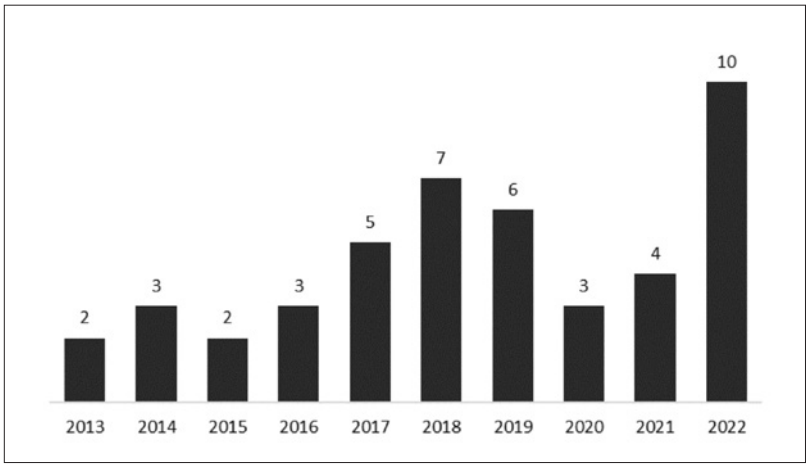
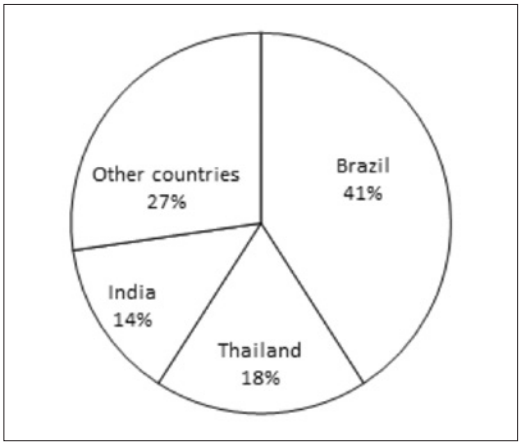


Figure 2 - Number of publications per year between the period of 2013 and 2022.

Table 1 shows the distribution of studies by sustainability dimension, according to the indicators evaluated in each work. During the period analyzed, the largest number of studies (15) focused on the environmental, economic, and social dimensions together. Seven studies focused on the environmental and economic dimensions, four on the environmental and social dimensions, and three on the economic and social dimensions. Additionally, nine studies focused exclusively on the environmental dimension and one on the social dimension. Five studies addressed sugarcane sustainability without emphasizing any specific dimension of sustainability. No studies were found focusing solely on the economic dimension of sustainability.

Figure 3 - Publications per countries where the studies were conducted between 2022 and 2023.



4.2. *Sugarcane sustainability indicators identification*

From sampled studies, 119 indicators were found in all three dimensions of sustainability. The economic dimension covered the highest number of indicators (38.7%), followed by environmental (31.1%) and social (30.3%).

4.2.1. *Environmental dimension*

The environmental dimension had 37 indicators in the Atmosphere and Water, Land and Biodiversity, Materials, and Energy themes. Of the Atmosphere and Water theme's indicators, Greenhouse gas emissions (GHG), Water use and Water quality were the most common (see

Table 1 - Frequency of studies by sustainability dimension addressed.

Dimensions (n = 44 articles)	*Frequency*	*Percentage*
Environmental + Economic + Social	15	34.1
Environmental + Economic	7	15.9
Environmental + Social	4	9.1
Economic + Social	3	6.8
Environmental	9	20.5
Social	1	2.3
None	5	11.4

Table 2 - Indicators under the environmental dimension.

Themes	*Indicators*		
	Designation	*Frequency*	*Sources*
Atmosphere and water	GHG emissions	7	De Jesus *et al*. (2019); Leal and Nogueira (2014); Lopez-Ortega *et al*. (2021); Poli *et al*. (2022); Prasara-A *et al*. (2019); Silalertruksa *et al*. (2015); Yani *et al*. (2022)
	Water use	2	Lopez-Ortega *et al*. (2021); Prasara-A *et al*. (2019)
	Water quality	3	Leal and Nogueira (2014); Yani *et al*. (2022); Lopez-Ortega *et al*. (2021)

Table 3 - Indicators under the social dimension.

Themes	*Indicators*		
	Designation	*Frequency*	*Source*
Equity and Decent Livelihood	Employment generation	6	Prasara and Gheewala (2016); Prasara-A *et al*. (2019); Prasara-A and Gheewala (2021); Leal and Nogueira (2014); Lopez-Ortega *et al*. (2021); Poli *et al*. (2022)
	Initiatives to promote the local community's welfare	2	De Jesus *et al*. (2019); Yani *et al*. (2022)

Table 2). The higher frequency of GHG emissions in the study sample indicates that researchers value it when measuring the sustainability of sugarcane production.

4.2.2. *Social Dimension*

The social dimension included 36 indicators under Labor Rights, Safety and Health, and Equity and Decent Livelihood themes. The most common indicators in this dimension were Employment generation and Initiatives to promote the local community's welfare, from the Equity and Decent Livelihoods themes. Six papers cited "Employment generation", reflecting researchers' strong belief in its impact on communities (see Table 3).

Six (6) additional social indicators were identified, which we believe are relevant and deserve to be highlighted in this study due to the authors' interest in them. These are Conflict with land rights, Wages, and Wage satisfaction from Equity and Decent Livelihoods, Forced labor in the field, Freedom of collective bargaining, and Accidents in the previous year from Labor Rights and Safety and Health.

4.3. *Economic Dimension*

The economic dimension had 46 indicators. The most common indicators in this dimension were Cane yield, Sugarcane productivity, Production and Profit, from the investment theme, and Distance to sugar mills from the Local Economy and Product Quality (see Table 4). Cane yield was the indicator most cited (3 times).

Therefore, according to the results, 16 common indicators were found. However, only five (5) indicators were measured. Water use, Cane yield, and Distance to the sugar mill were measured through interviews with sugarcane farm owners, while Employment generation was measured through interviews with workers, and management and Wage satisfaction were measured through interviews with farm workers. Most indicators (68.8%) were presented without measurement (see Table 5).

5. Discussions

The article reviewed the literature on the sustainability of sugarcane production and identi-

Table 4 - Indicators under the economic dimension.

Themes	*Indicators*		
	Designation	*Frequency*	*Sources*
Investment	Cane yield	3	Aguilar-Rivera (2019); Lopez-Ortega *et al*. (2021); Prasara and Gheewala (2016)
	Sugarcane productivity	2	De Jesus *et al*. (2019); Leal and Nogueira (2014)
	Sugarcane production	2	Aguilar-Rivera (2019); Yani *et al*. (2022)
	Profit	2	Lopez-Ortega *et al*. (2021); Yani *et al*. (2022)
Local Economy and Product Quality	Distance to sugar mills	2	Aguilar-Rivera (2019); Prasara and Gheewala (2016)

fied the most common indicators for assessing the sustainability of the sugarcane production systems. The results of Figure 2 show that more attention on this topic has increased after 2016, and this could be attributed to two important events, namely, the UN Sustainable Development Summit in 2015 and the entry of the Paris Agreement into force in 2016. These milestones have influenced governments, researchers, and societies to emphasize the importance of sustainable practices in sugarcane production systems. In practical terms, most studies (54.6%) present apparent gaps due to the non-inclusion of the three main dimensions in the same research, thus not reflecting the real effect of sugarcane production on the three main aspects of sustainability. Kristensen and Mosgaard (2020) and Rajeev *et al*. (2017) argue that for a production system to be considered sustainable, there must be a joint integration of the environmental, economic and social aspects of the value chain within the same framework. Therefore, not including the three main dimensions in studies may pose a risk to the conclusions being drawn about the sustainability of the system under assessment.

Climate change is now the target of global attention. It is reflected in several initiatives and agreements that aim to reduce its adverse impacts on agriculture, health, education, and other areas, contributing to greater awareness in the community. Therefore, the presence of 79.5% of articles discussing the environmental dimension of sustainability is a reflection of this concern with environmental issues, specifically in the cultivation of sugarcane, which contributes approximately 11% of the world's agricultural waste and 400 million tons of CO2 equivalent annually (BONSUCRO, 2023; Bordonal *et al*., 2018; De Figueiredo *et al*., 2010). On the other hand, the social dimension receives less attention. The weak presence of the social dimension in studies on sugarcane sustainability is in line with Massuça *et al*. (2023) findings. This situation is associated with the fact that it addresses aspects related to the well-being of communities, which is often challenging to define consensual methods of measurement and interpretation, leaving subjectivity and a lack of clarity in the definition and measurement of the corresponding indicators (Baffoe & Mutisya, 2015; Bubicz *et al*., 2019; Hale *et al*., 2019). Boström (2012) adds that the meaning of social sustainability remains unclear and does not have an evident scientific basis for measuring it. Similarly, Eizenberg and Jabareen (2017), Gaviglio *et al*. (2016), Janker *et al*. (2019), and Sidhoum (2018) emphasize that lack of cohesion in the perception of the definition of the social dimension creates confusion in determining the means of operationalization.

Although the environmental dimension receives the most attention, economic indicators were more prevalent in this study than environmental indicators. This scenario can be attributed to the fact that economic indicators are usual-

Table 5 - Description of common indicators.

Indicator	*Description*	*Measurement*
GHG emissions	Emissions of CO2, CH4, and N2O at each stage of the supply chain (van Eijck *et al*., 2014)	Not mentioned
Water use	Quantity of water required to irrigate and process crops within the plantation systems (Garcia-Bustamante *et al*., 2018; Prasara-A *et al*., 2019).	Interviews with sugarcane farm owners
Water quality	Chemical, physical and biological characteristics of water based on patterns of its use (Chapman, 2021).	Not mentioned
Employment generation	Number of annual full-time equivalent jobs generated by tons of sugarcane produced and processed (Lopez-Ortega *et al*., 2021; Prasara-A *et al*., 2019)	Interviews with workers and management
Initiatives to promote the local community's welfare	Initiatives carried out in communities to mitigate the negative impacts that certain activities may have on the community (Ahmad & Nomani, 2015).	Not measured
Conflict with land rights	Acts against farmers' rights in their land (Boone, 2019).	Not measured
Wages	Key agricultural activities' daily wages without a meal (Hassan & Kornher, 2022; Prasara-A *et al*., 2019).	Not mentioned
Wage Satisfaction	Workers' feelings towards their wages (Stander *et al*., 2019).	Interviews with farm workers
Forced labor in the field	Work required of anyone in a non-voluntary way (Machado *et al*., 2017).	Not mentioned
Freedom of collective bargaining of workers	Negotiation between organizations and employees to determine the terms and conditions of employment (Nwokocha, 2015).	Not mentioned
Accident in the previous year	Refers to the unexpected incident that usually causes harm or injury.	Not mentioned
Cane yield	Quantity of cane produced within a given period per unit of land area harvested (Fischer, 2015).	Interviews with sugarcane farm owners
Sugarcane productivity	Amount produced by farm given a set of resources and inputs (FAO, 2017).	Not mentioned
Sugarcane production	Quantity of the product sold or consumed and normally recorded in tons (FAO, 2013)	Not mentioned
Profit	Financial gain made when the income exceeds expenses, costs, and taxes (Nadaraja *et al*., 2021)	Not mentioned
Distance to sugar mills	Refers to the distance from the sugarcane field production to the factory.	Interview with sugarcane farm owners

ly quantitative and, therefore, apparently easier to measure in the researchers' view compared to environmental indicators, which are more complex (Cruz *et al*., 2018). However, the results found in the present study are contrary to those obtained by some studies, which address sustainability indicators in agricultural production systems despite not mentioning specific crops. Nadaraja *et al*. (2021) found the highest number of environmental indicators, followed by social and economic indicators. Unlike this, Bathaei and Štreimikienė (2023) found the highest number of indicators in the environmental dimension, followed by economic and social. These findings show that the selection of indicators per dimension to be studied by the different authors does not follow a specific rule but rather depends on the researcher's interest, the research objectives and the study context.

Of the 16 common indicators identified, GHG emissions, Employment generation, Water quality and Sugarcane yield had the highest frequen-

cy in the studies. The high frequency of these indicators is associated with the fact that sugarcane is a crop focused on income and, therefore, requires large areas of land, a large workforce, and the use of large quantities of agrochemicals. Due to the intense application of fertilizers, pesticides, herbicides, and the recurrent practice of burning in the fields, this crop contributes to the emission of large quantities of greenhouse gases and negative effects on water quality. This situation becomes a dilemma for this sector, which, on the one hand, struggles to increase the yield of sugarcane to meet the demands of the international market and, on the other, to reduce the emission of GHGs into the atmosphere to comply with global requirements. Nadaraja *et al*. (2021) and Bathaei and Štreimikienė (2023) also noted these indicators as common and vital to agricultural sustainability evaluation.

Most selected indicators (68.8%) were not measured in the studied sample. Bélanger *et al*. (2012) emphasize that indicators are used to simplify, quantify and communicate efficiently. In this context, if the indicators are not quantified, they do not fulfill the function for which they were developed. Some of the challenges in measuring indicators in sugarcane production are related to the high cost of equipment, the subjectivity of information due to dependence on data provided by the employer itself, and the variations of the payment mode in this sector (Lopez-Ortega *et al*., 2021; Nadaraja *et al*., 2021; Prasara-A *et al*., 2019). To fix this problem and ensure that available, measurable and applicable indicators are chosen, they must be selected using a bottom-up approach that includes all the people with a stake in the value chain. This way, users can also easily adopt and accept the indicators.

6. Conclusions

Although the environmental dimension is addressed in most studies, indicators of the economic dimension were frequent due to their ease of identification and measurement. The social dimension continues to receive the least attention from authors in studies evaluating the sustainability of sugarcane, despite the significant pressure that the sugar sector has faced in recent years to pay more attention to the conditions of workers and the communities where production takes place.

The selection of sustainability indicators and dimensions for study does not follow a specific rule but rather depends on the researcher's interest, research objectives and the context of the study itself. Overall, 16 common indicators used to assess the sustainability of sugarcane were identified and should receive special attention in future studies on this crop. For instance, indicators such as GHG emissions; water use, water quality, employment generation, and Initiatives to promote the local community welfare, crop yield, sugarcane productivity, sugarcane production, profit and distance to sugar mills are considered to have the highest impact on sustainability in sugarcane production. These results indicate that greater attention should be paid to these indicators in the sugarcane production process to enable more efficient management and ensure sustainability across different production systems. Given the nature of cash crops primarily aimed at commerce, utilizing large land areas and requiring substantial labor, these indicators can also be applied in analyzing the sustainability of other crops such as soybeans, tobacco, sesame, and others, while acknowledging the specific characteristics of each crop. However, the indicators identified may not be universally applicable due to various factors associated with sugarcane production, such as geographical location, cultural differences, and political influences. One of the major challenges encountered in the selected studies was the difficulty in measuring a significant portion of the identified indicators due to their complexity, which could limit their utility for different stakeholders. Therefore, it is essential to identify and analyze the most common indicators used in sugarcane across different geographic areas and conditions, ensuring that these indicators are adapted to the specific context under study.

Due to its focus, it is important to employ bottom-up approaches for indicator selection in further research. This approach allows for the incorporation of perspectives from various stakeholders and considers the diverse realities of sugarcane production worldwide, as exemplified by the SustenAgro Support System.

Finally, it is important to conduct studies that evaluate the sustainability of sugarcane in the production process in the field and during the transformation phase in the factory. This approach will provide insights into sustainability and its influencing factors across different contexts and perspectives. It will also help identify the most relevant indicators for each phase of sugarcane production.

Acknowledgments

This research was supported by FCT - Fundação para a Ciência e Tecnologia under the projects UIDB/04011/2020 (https://doi.org/10.54499/UIDB/04011/2020) and UIDB/04007/2020 (https://doi.org/10.54499/UIDB/04007/2020).

References

Aguilar-Rivera N., 2019. A framework for the analysis of socioeconomic and geographic sugarcane agro industry sustainability. *Socio-Economic Planning Sciences*, 66: 149-160. https://doi.org/10.1016/j.seps.2018.07.006.

Aguilar-Rivera N., 2022. Bioindicators for the sustainability of sugar agro-industry. *Sugar Tech*, 24(3): 651-661. https://doi.org/10.1007/s12355-021-01105-z.

Ahmad S., Nomani A., 2015. Problems of corporate social responsibility in Sugarcane value chain in Utter Pradesh: an analysis through integrated model of CCSR. *Management Studies and Economic Systems*, 1(4): 207-212.

Baas J., Schotten M., Plume A., Côté G., Karimi R., 2020. Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. *Quantitative science studies*, 1(1): 377-386. https://doi.org/10.1162/qss_a_0001.

Baffoe G., Mutisya E., 2015. Social sustainability: A review of indicators and empirical application. *Environmental Management and Sustainable Development*, 4(2): 242-262. https://doi.org/10.5296/emsd.v4i2.8399.

Bathaei A., Štreimikienė D., 2023. A Systematic Review of Agricultural Sustainability Indicators. *Agriculture*, 13(2): 241. https://doi.org/10.3390/agriculture13020241.

Bélanger V., Vanasse A., Parent D., Allard G., Pellerin D., 2012. Development of agri-environmental indicators to assess dairy farm sustainability in Quebec, Eastern Canada. *Ecological indicators*, 23: 421-430. https://doi.org/10.1016/j.ecolind.2012.04.027.

Birkle C., Pendlebury D., Schnell J., Adams J., 2020. Web of Science as a data source for research on scientific and scholarly activity. *Quantitative Science Studies*, 1(1): 363-376. https://doi.org/10.1162/qss_a_00018.

BONSUCRO, 2023. *Where do GHG emissions in sugarcane come from?* Retrieved from https://bonsucro.com/ghg-emissions-in-sugarcane/ (acessed at 21.02.2024).

Boone C., 2019. Legal empowerment of the poor through property rights reform: Tensions and trade-offs of land registration and titling in sub-Saharan Africa. *The Journal of Development Studies*, 55*(*3): 384-400. https://doi.org/10.1080/00220388.2018.1451633.

Bordonal R.O., Carvalho J.L.N., Lal R., Figueiredo E.B., Oliveira B.G., La Scala N., 2018. Sustainability of sugarcane production in Brazil. A review. *Agronomy for Sustainable Development*, 38: 1-23. https://doi.org/10.1007/s13593-018-0490-x.

Boström M., 2012. A missing pillar? Challenges in theorizing and practicing social sustainability: introduction to the special issue. *Sustainability: Science, practice and policy*, 8(1): 3-14. https://doi.org/10.1080/15487733.2012.11908080.

Bubicz M.E., Barbosa-Póvoa A.P.F.D., Carvalho A., 2019. Incorporating social aspects in sustainable supply chains: Trends and future directions. *Journal of Cleaner Production*, 237. https://doi.org/10.1016/j.jclepro.2019.06.331.

Chapman D.V., 2021. *Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring*. London: CRC Press, 656 pp. https://doi.org/10.1201/9781003062103.

Corvo L., Pastore L., Antonelli A., Petruzzella D., 2021. Social impact and sustainability in short food supply chains: An experimental assessment tool. *New Medit*, 20(3): 175-189. https://doi.org/10.30682/nm2103l.

Coutinho H.L.C., Turetta A.P.D., Monteiro J.M.G., Castro S.S., Pietrafesa J.P., 2017. Participatory sustainability assessment for sugarcane expansion in Goiás, Brazil. *Sustainability*, 9*(*9): 1573. https://doi.org/10.3390/su9091573.

Cruz J.F., Mena Y., Rodríguez-Estévez V., 2018. Methodologies for assessing sustainability in farming systems. In: Gokten S., Gokten P.O. (eds.), *Sustainability Assessment and Reporting,* IntechOpen, pp. 33-58. https://doi.org/10.5772/intechopen.79220.

De Figueiredo E.B., Panosso A.R., Romão R., La Scala N., 2010. Greenhouse gas emission associ-

ated with sugar production in southern Brazil. *Carbon balance and management*, 5: 1-7. https://doi.org/10.1186/1750-0680-5-3.

De Jesus K.R.E.D., Torquato S.A., Machado P.G., Brumatti Zorzo C.R., Cardoso B.O., Leal M.R.L.V., Picoli M.C.A., Ramos R.C., Dalmago G.A., Capitani D.H.D., Duft D.G., Suárez J.G., Pierozzi J.I., Trevelin L.C., Moreira D.A., 2019. Sustainability assessment of sugarcane production systems: SustenAgro Decision Support System. *Environmental Development*, 32. https://doi.org/10.1016/j.envdev.2019.05.003.

Depetris-Chauvin N., Fernandez Olmos M., Hu W., Malorgio G., 2023. Costs and benefits of sustainability-oriented innovation in the agri-food industry: A review. *New Medit*, 22(3): 23-45.

Duarte C.G., Gaudreau K., Gibson R.B., Malheiros T.F., 2013. Sustainability assessment of sugarcane-ethanol production in Brazil: A case study of a sugarcane mill in São Paulo state. *Ecological indicators*, 30: 119-129. https://doi.org/10.1016/j.ecolind.2013.02.011.

Eizenberg E., Jabareen Y., 2017. Social sustainability: A new conceptual framework. *Sustainability*, 9(1): 68.

FAO, 2013. *Sustainability Assessment of Food and Agricultural Systems (SAFA) Guidelines*. Rome: FAO.

FAO, 2017. *Productivity and Efficiency Measurement in Agriculture*. Rome: FAO.

Fischer R., 2015. Definitions and determination of crop yield, yield gaps, and of rates of change. *Field Crops Research*, 182: 9-18.

Gamboa G., Kovacic Z., Di Masso M., Mingorría S., Gomiero T., Rivera-Ferré M., Giampietro M., 2016. The complexity of food systems: Defining relevant attributes and indicators for the evaluation of food supply chains in Spain. *Sustainability*, 8(6): 515.

Gani A., Asjad M., Talib F., Khan Z.A., Siddiquee A.N., 2021. Identification, ranking and prioritisation of vital environmental sustainability indicators in manufacturing sector using pareto analysis cum best-worst method. *International Journal of Sustainable Engineering*, 14(3): 226-244.

Garcia-Bustamante C.A., Aguilar-Rivera N., Zepeda-Pirron M., Armendariz-Arnez C., 2018. Development of indicators for the sustainability of the sugar industry. *Environmental & Socio-Economic Studies*, 6(4): 22-38. https://doi.org/10.2478/environ-2018-0025.

Gaviglio A., Bertocchi M., Marescotti M. E., Demartini E., Pirani A., 2016. The social pillar of sustainability: a quantitative approach at the farm level. *Agricultural and Food Economics*, 4(1): 1-19.

Gayatri S., Gasso-tortajada V., Vaarst M., 2016. Assessing sustainability of smallholder beef cattle farming in Indonesia: A case study using the FAO SAFA framework. *Journal of Sustainable Development*, 9(3).

Gnansounou E., Alves C.M., Pachón E.R., Vaskan P., 2017. Comparative assessment of selected sugarcane biorefinery-centered systems in Brazil: A multi-criteria method based on sustainability indicators. *Bioresource technology*, 243: 600-610. https://doi.org/10.1016/j.biortech.2017.07.004.

Hale J., Legun K., Campbell H., Carolan M., 2019. Social sustainability indicators as performance. *Geoforum*, 103: 47-55.

Hall R., Scoones I., Tsikata D., 2017. Plantations, outgrowers and commercial farming in Africa: agricultural commercialisation and implications for agrarian change. *The Journal of Peasant Studies*, 44(3): 515-537.

Hassan M.F., Kornher L., 2022. Farm wage and Rice Price dynamics in Bangladesh. *Food Security*, 14(1): 127-146.

Janker J., Mann S., 2020. Understanding the social dimension of sustainability in agriculture: a critical review of sustainability assessment tools. *Environment, Development and Sustainability*, 22(3): 1671-1691.

Janker J., Mann S., Rist S., 2019. Social sustainability in agriculture–A system-based framework. *Journal of Rural Studies*, 65: 32-42.

Joglekar S.N., Dalwankar G., Qureshi N., Mandavgane S.A., 2022. Sugarcane valorization: selection of process routes based on sustainability index. *Environmental Science and Pollution Research*: 1-14.

Karvonen J., Halder P., Kangas J., Leskinen P., 2017. Indicators and tools for assessing sustainability impacts of the forest bioeconomy. *Forest ecosystems*, 4(1): 1-20.

Kralisch D., Ott D., Gericke D., 2015. Rules and benefits of life cycle assessment in green chemical process and synthesis design: a tutorial review. *Green Chemistry*, 17(1): 123-145.

Kristensen H.S., Mosgaard M.A., 2020. A review of micro level indicators for a circular economy–moving away from the three dimensions of sustainability? *Journal of Cleaner Production*, 243: 118531.

Lacovidou E., Voulvoulis N., 2018. A multi-criteria sustainability assessment framework: development and application in comparing two food waste management options using a UK region as a case study. *Environmental Science and Pollution Research*, 25: 35821-35834.

Latruffe L., Diazabakana A., Bockstaller C., Desjeux

Y., Finn J., Kelly E., Uthes S., 2016. Measurement of sustainability in agriculture: a review of indicators. *Studies in Agricultural Economics*, 118(3): 123-130.

Leal M.R.L.V., Nogueira L.A.H., 2014. The sustainability of sugarcane ethanol: The impacts of the production model. *Chemical Engineering Transactions*, 37: 835-840. https://doi.org/10.3303/CET1437140.

Li T., Hua F., Dan S., Zhong Y., Levey C., Song Y., 2020. Reporting quality of systematic review abstracts in operative dentistry: An assessment using the PRISMA for Abstracts guidelines. *Journal of Dentistry*, 102.

Lopez-Ortega M.G., Guadalajara Y., Junqueira T.L., Sampaio I.L.M., Bonomi A., Sanchez A., 2021. Sustainability analysis of bioethanol production in Mexico by a retrofitted sugarcane industry based on the Brazilian expertise. *Energy*, 232(12). https://doi.org/10.1016/j.energy.2021.121056.

Machado P.G., Rampazo N.A.M., Picoli M.C.A., Miranda C.G., Duft D.G., de Jesus K.R.E., 2017. Analysis of socioeconomic and environmental sensitivity of sugarcane cultivation using a Geographic Information System. *Land Use Policy*, 69: 64-74.

Marta-Costa A., Trigo A., Costa J.M., Fragoso R., 2022. Standards and indicators to assess sustainability: the relevance of metrics and inventories. In: Costa J.M., Catarino S., Escalona J.M., Comuzzo P. (eds), *Improving Sustainable Viticulture and Winemaking Practices*. Amsterdam: Elsevier, pp. 391-414.

Massuça J., Marta-Costa A., Lucas M.R., 2023. Social dimension of sustainability: assessment in the agribusiness context. *New Medit*, 22(2): 63-80.

Mokrani A., Ben Nasr J., Sai M.B., Bachta M.S., 2022. Sustainability assessment of Tunisian olive growing systems. *New Medit*, 21(4): 3-13.

Nadaraja D., Lu C., Islam M.M., 2021. The sustainability assessment of plantation agriculture-a systematic review of sustainability indicators. *Sustainable Production and Consumption*, 26: 892-910.

Naisola-Ruiter V., 2022. The Delphi technique: a tutorial. *Research in Hospitality Management*, 12(1): 91-97.

Nwokocha I., 2015. Employers and the enhancement of industrial harmony in private sector organizations in Nigeria. *IOSR Journal of Humanities and Social Science*, 20(5): 28-35.

Pham L.V., Smith C., 2014. Drivers of agricultural sustainability in developing countries: A review. *Environment Systems and Decisions*, 34: 326-341.

Poli F.M.L., Islas-Samperio J.M., Bustamante C.G.A., Rivero J.S.C., Grande-Acosta G.K., Gallardo-Alvarez R.M., Escobedo C.A., 2022. Sustainability Assessment of Solid Biofuels from Agro-Industrial Residues Case of Sugarcane Bagasse in a Mexican Sugar Mill. *Sustainability*, 14(3): 25. https://doi.org/10.3390/su14031711

Prasara-A J., Gheewala S.H., 2016. Sustainability of sugarcane cultivation: case study of selected sites in north-eastern Thailand. *Journal of Cleaner Production*, 134: 613-622. https://doi.org/10.1016/j.jclepro.2015.09.029.

Prasara-A J., Gheewala S.H., 2021. An assessment of social sustainability of sugarcane and cassava cultivation in Thailand. *Sustainable Production and Consumption*, 27: 372-382. https://doi.org/10.1016/j.spc.2020.11.009.

Prasara-A J., Gheewala S.H., Silalertruksa T., Pongpat P., Sawaengsak W., 2019. Environmental and social life cycle assessment to enhance sustainability of sugarcane-based products in Thailand. *Clean Technologies and Environmental Policy*, 21(7): 1447-1458. https://doi.org/10.1007/s10098-019-01715-y.

Rajeev A., Pati R.K., Padhi S.S., Govindan K., 2017. Evolution of sustainability in supply chain management: A literature review. *Journal of Cleaner Production*, 162: 299-314.

Rasmussen L.V., Bierbaum R., Oldekop J.A., Agrawal A., 2017. Bridging the practitioner-researcher divide: Indicators to track environmental, economic, and sociocultural sustainability of agricultural commodity production. *Global environmental change*, 42: 33-46.

Sawaengsak W., Olsen S.I., Hauschild M.Z., Gheewala S.H., 2019. Development of a social impact assessment method and application to a case study of sugarcane, sugar, and ethanol in Thailand. *International Journal of Life Cycle Assessment*, 24(11): 2054-2072. https://doi.org/10.1007/s11367-019-01624-8.

Shi L., Han L., Yang F., Gao L., 2019. The evolution of sustainable development theory: Types, goals, and research prospects. *Sustainability*, 11(24): 7158.

Shukor S.A., Ng G.K., 2022. Environmental indicators for sustainability assessment in edible oil processing industry based on Delphi Method. *Cleaner Engineering and Technology*, 10: 100558.

Sidhoum A.A., 2018. Valuing social sustainability in agriculture: An approach based on social outputs' shadow prices. *Journal of Cleaner Production*, 203: 273-286.

Silalertruksa T., Gheewala S.H., Pongpat P., 2015. Sustainability assessment of sugarcane biorefinery and molasses ethanol production in Thailand using

eco-efficiency indicator. *Applied Energy*, 160: 603-609. https://doi.org/10.1016/j.apenergy.2015.08.087.

Silalertruksa T., Pongpat P., Gheewala S.H., 2017. Life cycle assessment for enhancing environmental sustainability of sugarcane biorefinery in Thailand. *Journal of Cleaner Production*, 140: 906-913. https://doi.org/10.1016/j.jclepro.2016.06.010.

Souto S., Bezerra R., Gonçalves S., Santos M., Gurgel M., 2024. Conflicts and socioenvironmental injustice in the Acaú-Goiana Extractive Reserve. *Ambiente & Sociedade*, 27: e02253.

Stander M.W., De Coning J.A., Rothmann S., 2019. Do wage and wage satisfaction compensate for the effects of a dissatisfying job on life satisfaction? *SA - Journal of Industrial Psychology*, 45(1): 1-11.

TraceX Technologies, 2023. *Measuring farm sustainability metrics for better agriculture*. TraceX Technologies. Retrieved from https://tracextech.com/measuring-farm-sustainability-metrics/ (acessed at 31.01.2024).

Turetta A.P.D., Kuyper T., Malheiros T.F., Coutinho H.L.D.C., 2017. A framework proposal for sustainability assessment of sugarcane in Brazil. *Land Use Policy*, 68: 597-603. https://doi.org/10.1016/j.landusepol.2017.08.011.

Van Eijck J., Romijn H., Smeets E., Bailis R., Rooijakkers M., Hooijkaas N., Faaij A., 2014. Comparative analysis of key socio-economic and environmental impacts of smallholder and plantation based jatropha biofuel production systems in Tanzania. *Biomass and Bioenergy*, 61: 25-45.

Waas T., Hugé J., Block T., Wright T., Benitez-Capistros F., Verbruggen A., 2014. Sustainability assessment and indicators: Tools in a decision-making strategy for sustainable development. *Sustainability*, 6(9): 5512-5534.

World Commission on Environment and Development, 1987. *Our Common Future*. Oxford: Oxford University Press, pp. 372.

Yani M., Machfud S., Asrol M., Hambali E., Papilo P., Mursidah S., Marimin M., 2022. An Adaptive Fuzzy Multi-Criteria Model for Sustainability Assessment of Sugarcane Agroindustry Supply Chain. *Ieee Access*, 10: 5497-5517. https://doi.org/10.1109/access.2022.3140519.

Zhao P., Ali Z.M., Ahmad Y., 2023. Developing indicators for sustainable urban regeneration in historic urban areas: Delphi method and analytic hierarchy process (AHP). *Sustainable Cities and Society*, 99: 104990.