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SHORT COMMUNICATION

Use of Delphi methodology to select sustainability indicators on dairy farms: an exploration of environmental, economic, social and animal welfare dimensions

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ABSTRACT. Sustainable livestock production is essential to ensure the availability of food and resources, and to address the social, economic, and environmental challenges that threaten conventional livestock production. While there is consensus among economic, social, and scientific groups on the need to assess sustainability to make decisions that protect resources for present and future generations, there are few sustainability assessment tools that address it holistically. The aim of this study was to develop an assessment tool applicable to farms by identifying the indicators currently applied in dairy farms, based on a systematic literature review and expert opinion. This study used the Delphi methodology to explore sustainability indicators at the farm level. A panel of seven expert researchers and academics in livestock sustainability and animal welfare participated in the study. A high level of consensus was found for 15 economic indicators, 14 social indicators, 20 environmental indicators, and 16 animal welfare indicators. Some indicators, such as financial autonomy, transmissibility, cow and labor productivity, husbandry system, labor intensity, community bonding, labor satisfaction, biodiversity, crop rotation, fertilization, manure management, and water management, showed a high level of consensus and were considered useful in assessing sustainability on dairy farms. In addition, livestock sustainability experts reached a high consensus on 16 animal welfare indicators that could be useful in assessing farm sustainability. These results provide a solid basis for sustainability indicators in the economic, social, environmental, and animal welfare dimensions, which could serve as a basis for developing a sustainability assessment tool for dairy farms.

Keywords: sustainable livestock production; assessment indicators; sustainability dimensions; animal welfare; Delphi methodology.

INTRODUCTION

Continuous access to food and resources is vital for sustaining and advancing all human endeavors. However, livestock farming encounters social, economic, and environmental challenges that jeopardize its capacity to fulfill the current and future requirements of humanity (Munyaneza, 2018). Addressing these challenges necessitates the creation of innovative agricultural technologies and methods that are environmentally sustainable, readily accessible, and efficient for producers, while simultaneously fostering increased food productivity and mitigating adverse impacts on human and animal health (Velten *et al*., 2015; Henning & Jordaan, 2016).

Given the variety of impacts that conventional livestock production can have on social, economic, and environmental aspects, sustainable livestock production has gained relevance in recent years (Zahm *et al*., 2008). Although significant advances in crop and livestock productivity have been made it is still uncertain if it will be possible to sustain this progress in the future (Velten *et al*., 2015)

The sustainability challenges encountered in livestock farming may exhibit variation across different countries, regional contexts, or even production systems (Castillo-Rodríguez *et al*., 2012; Salinas, 2014). For example, in High income countries, key challenges in terms of sustainability include diversification of a limited range of commodities and addressing environmental concerns raised by social groups, especially about significant nutrient loss and excessive use of pesticides (Zhen & Routray, 2003). Conversely, in countries with lower and middle incomes, the primary aim is to sustain food production while conserving the current resource foundation (Munyaneza, 2018).

In every sustainability initiative, it's essential to have a clear understanding of the operational definition of the "sustainability concept" to initiate any project (Munyaneza, 2018; Zahm *et al*., 2008). Even if the fundamental essence of sustainability is apparent, its practical implementation can differ based on various individual viewpoints (Munyaneza, 2018; Seghezzo, 2009). The word "sustainable" originates from the Latin word "subtenir," which translates to "to sustain" or "to support from below" (Munyaneza, 2018). The most recognized definition of sustainability or sustainable development offered by the World Commission on Environment and Development (WCED, 1987), is the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (chap. II, para. 1). However, some authors have pointed out that this definition is subjective creating a problem when trying to apply it (Munyaneza, 2018; Brunett *et al*., 2006; Van Passel *et al*., 2007; Ruiz *et al*., 2017). On the other hand, a more recent definition has been proposed by Broom (2014) who defines sustainability as: "A system or procedure is sustainable if it is acceptable now and if its expected future effects are acceptable, in particular in relation to resource availability, consequences of functioning, and morality of action", emphasizing other aspects of sustainability such as the morality of action, and considering a system as not sustainable if it, for example, has negatives effects on animal welfare (p. 353).

An essential difficulty arises in delineating the concept of "need," as what one person regards as essential requirements, others might view as mere desires (Munyaneza, 2018; Cox & Ziv, 2005). This ambiguity suggests that what may be deemed sustainable for one individual could be deemed moderately or entirely unsustainable for another (Munyaneza, 2018). Furthermore, Seghezzo (2009) highlights additional shortcomings in the definition of sustainability, including its anthropocentric perspective, the excessive emphasis on economic factors, and the neglect of environmental, social, and animal welfare dimensions.

Sustainability assessment through indicators is proposed as the approach to implement the concept of sustainability (Munyaneza, 2018; Van Passel *et al*., 2007; Binder *et al*., 2010; Broom, 2021). Presently, multiple methodologies have been created to evaluate the sustainability of cattle production on individual farms (Attia *et al*., 2021; Salinas, 2014; Meul *et al*., 2012; Verduna *et al*., 2020; Pérez Lombardini *et al*., 2021), however, these tools may not be suitable for the farm reality of different countries. One solution to this problem is to adapt existing methodologies to the specific context of the country in which they are applied (Munyaneza, 2018; Ruiz *et al*., 2017).

The selection of indicators is considered a critical step during sustainability assessment, as these have an impact on the conclusions and outcomes of interventions. Factors affecting sustainability outcomes can be diverse, such as household characteristics, different types of farms, and different environments where livestock farming takes place (Munyaneza, 2018; Van Calker *et al*., 2008). Therefore, understanding these factors is critical to guide any intervention aimed at improving sustainability. For the selection of sustainability indicators, various methodologies have been utilized, including expert-driven and stakeholder-driven approaches (Munyaneza, 2018; Gómez-Ravelo *et al*., 2013).

One methodology that can be used to obtain a consensus of informed opinions from subject matter experts, overcoming individual limitations and reflecting a complete and broad view of sustainability, is the Delphi method (Gómez-Ravelo *et al*., 2013). The Delphi method involves assembling a panel of experts within the pertinent research field, rather than employing a random sample representative of a target population (Ahmad & Yew Wong, 2019; Keeney *et al*., 2001). In contrast to household surveys, there is not a standard sample size requirement for the Delphi technique (Munyaneza, 2018; Henning & Jordaan, 2016). Regarding the number of experts involved, Varela-Ruiz *et al.* (2012) propose that a range of seven to 30 experts is necessary to ensure reliable outcomes.

This paper applies the Delphi methodology, a reliable top-down approach to reach consensus and unify criteria on a specific topic, to select the most appropriate indicators to create a sustainability assessment tool for dairy cattle farms.

MATERIAL AND METHODS

The study was conducted between January and April 2023. For the selection of indicators, an initial list was compiled via a systematic review of scientific literature, which included indicators currently used to assess livestock sustainability in economic, social, environmental, and animal welfare dimensions.

This initial list, used as the basis for the Delphi survey, consisted of 24 indicators for the economic dimension, 19 indicators for the social dimension, 31 indicators for the environmental dimension, and 16 indicators for animal welfare.

Afterward, the survey was distributed via email to 20 researchers. These specialists were chosen due to their qualifications, background in the dairy industry, proficiency in sustainable livestock agriculture, accessibility, and eagerness to engage in the survey.

The Delphi survey consisted of one round in which the list of indicators was initially presented to the experts. Each indicator was evaluated in terms of usefulness, ease of evaluation, cost of implementation, and importance in sustainability. The experts scored the indicators using a 3-point scale (1= Not useful at all; 2= Useful; and 3= Very useful). Once the questionnaires from the first round were collected, mean scores, standard deviation, and coefficient of variation were calculated for each indicator (Figure 1).

The degree of agreement achieved plays a crucial role in determining whether additional rounds are necessary in the research process (Henning & Jordaan, 2016; Zinn *et al*., 2001). To gauge the levels of consensus, the coefficient of variation (CV) was utilized, following the classifications outlined by English and Kernan (1976) and Henning and Jordaan (2016), where we considered: a good level of consensus, indicating no need for further rounds ($0 \leq CV \leq 0.5$); a less satisfactory consensus, possibly warranting another round ($0.5 < CV \leq 0.8$); and a poor level of consensus, necessitating another round ($0.8 \leq CV$).

Furthermore, the standard deviation serves as a metric for evaluating the spread of values within a population (Grobbelaar, 2007). In this research, the degree of agreement identified by Grobbelaar (2007) and subsequently by Henning and Jordaan (2016) was utilized as a reference for making decisions based on the standard deviation (SD), with classifications as follows: high consensus ($0 \leq SD \leq 1$); reasonable or acceptable consensus ($1.01 \leq SD \leq 1.49$); low consensus ($1.5 \leq SD \leq 2$); and no consensus ($2 \leq SD$).

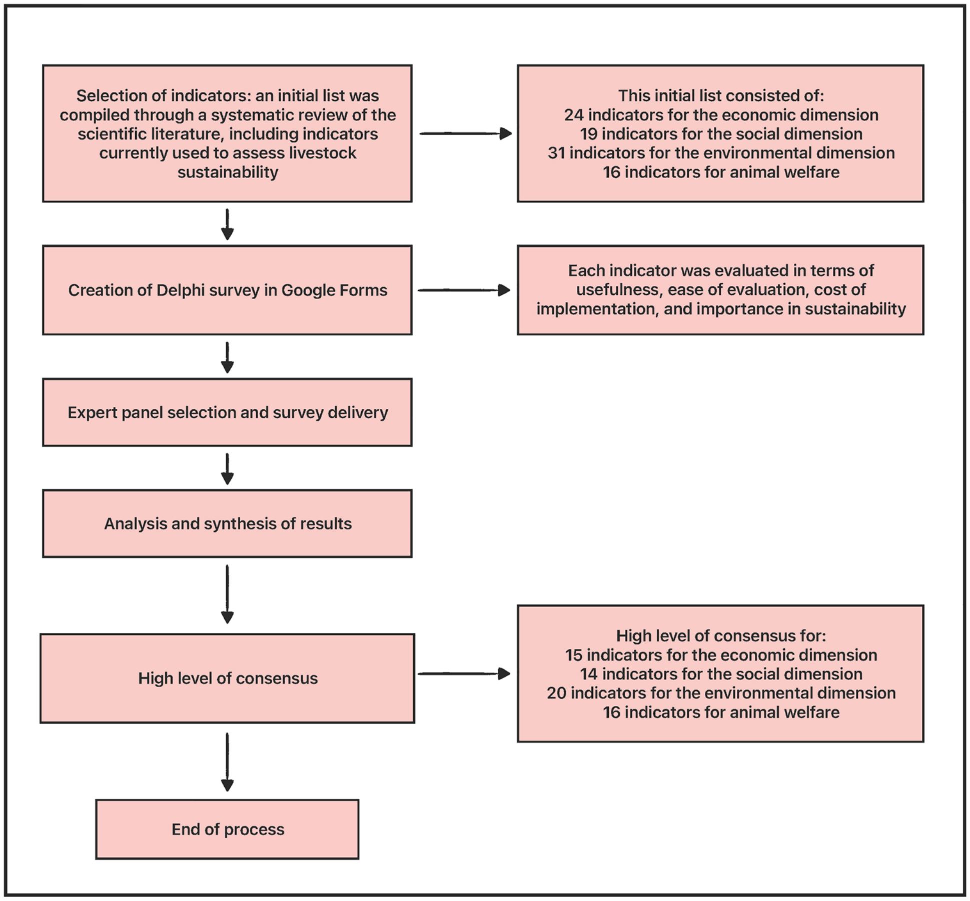

Figure 1.
Flowchart of Delphi methodology used in the study.

RESULTS AND DISCUSSION

Concerning the number of experts, a response rate of 35% was obtained, which corresponds to seven experts. According to Varela-Ruiz *et al.* (2012), the minimum number of experts to obtain valid results in the Delphi methodology is seven, so despite this response rate, it was possible to apply the methodology in the study. In order to achieve an adequate selection of livestock sustainability indicators, the expert panel was composed of researchers in livestock sustainability and animal welfare, dairy industry actors familiar with the components and challenges of livestock sustainability from Chile, Colombia, Brazil, Uruguay and Argentina, together with one person from Holland.

Once the experts' initial responses were obtained, the coefficient of variation (CV) rule proposed by English and Kernan (1976) was applied to measure the level of consensus and the need for a second round. It was observed that all indicators presented a high and satisfactory level of consensus ($0 \leq CV \leq 0.8$) for each of the dimensions. This means that it was not necessary to resort to a second round among the experts (Table 1).

Next, the standard deviation (SD) analysis, proposed by Grobbelaar (2007), was carried out for each indicator to determine which of them would be part of the final farm sustainability assessment tool. This analysis resulted in a high level of consensus for 15 economic indicators, 14 social indicators (Table 1), 20 environmental indicators, and 16 animal welfare indicators (Table 1).

Henning and Jordaan (2016) similarly utilized the standard deviation approach to ascertain consensus within the Delphi methodology. They aimed to identify the criteria utilized by banks in providing credit to farmers and producers. Like the current study, their findings suggested that employing standard deviation (SD) yielded reliable outcomes in assessing the level of consensus among Delphi methodology experts.

Table 1 displays the indicators that achieved a high level of consensus among the experts. Notably, for economic sustainability, accounting indicators are prominent, along with indicators aiding in the assessment of production costs, consistent with the findings of Henning and Jordaan

(2016). Moreover, Galioto *et al.* (2017) highlighted that the predominant economic indicators in dairy cattle farms revolve around the correlation between production costs and equivalent liters of milk, as well as profitability indicators encompassing intangible aspects like product quality and production methods. These conclusions align with the results of the current study and are corroborated by prior research conducted by Munyaneza (2018), Galioto *et al.* (2017),

Table 1.
Sustainability indicators for the economic and social dimensions were obtained by applying the Delphi methodology. The mean ($\bar{x}$), standard deviation (SD) and coefficient of variation (CV) of the scores for each indicator are provided.

	Economic dimension	$\bar{x}$	**SD**	**CV**
1	Economic viability	2.86	0.58	0.20
2	Financial autonomy	2.00	0.58	0.29
3	Transmissibility	1.86	1.15	0.62
4	Efficiency of production processes	2.00	0.58	0.29
5	Income per liter of milk	2.86	0.58	0.20
6	Cow productivity	3.00	0.00	0.00
7	Labour productivity	3.00	0.00	0.00
8	Feed conservation	2.57	1.00	0.39
9	Animal disease control (vaccination and parasite control)	2.86	0.58	0.20
10	Breeding system	2.71	1.15	0.43
11	Forage self-sufficiency	2.29	1.15	0.51
12	Safety, quality and transparency of production activities	2.43	0.58	0.24
13	Gross dairy farm income	2.71	1.15	0.43
14	PIB contribution	1.86	1.15	0.62
15	Land productivity	2.57	1.00	0.39
	Economic specialization rate *	2.00	1.53	0.76
	Sensitivity to government aid *	1.43	1.53	1.07
	Income over feed cost *	2.14	2.65	1.23
	Herd vigilance *	2.00	1.53	0.76
	Profitability *	2.29	1.53	0.67
	Feed cost expenditure *	2.43	1.53	0.63
	SOCIAL DIMENSION	$\bar{x}$	**SD**	**CV**
1	Level of schooling	3.00	0.00	0.00
2	Work intensity	2.71	0.58	0.21
3	Quality of life	2.86	0.58	0.20
4	Community involvement	2.71	0.58	0.21
5	Collective work	2.43	0.58	0.24
6	Hygiene and safety	2.57	1.00	0.39
7	Level of training of the farm manager	2.57	0.00	0.00
8	Generational transition	2.71	0.58	0.21
9	Risk of abandonment	2.57	1.00	0.39
10	Work satisfaction	2.71	0.58	0.21
11	Economic dependence	2.14	0.00	0.00
12	Diversification of activities on the farm	2.71	0.58	0.21
13	Labor rights	2.86	0.58	0.20
14	Cultural diversity	2.43	0.58	0.24
	Employment generation *	2.43	1.53	0.63
	Quality of facilities *	2.29	1.53	0.67
	Empowerment of women *	2.43	1.53	0.63
	Labor efficiency *	2.29	1.53	0.67

* Indicators that reached a low level of consensus in the Delphi methodology are shown in italics. These indicators were eliminated from the final sustainability list.

Table 1. (Continued)
Sustainability indicators for the environmental and animal welfare dimensions were obtained by applying the Delphi methodology. The mean (x̄), standard deviation (SD) and coefficient of variation (CV) of the scores for each indicator are provided.

	Economic dimension	**x̄**	**SD**	**CV**
1	Crop biodiversity	2.29	0.58	0.25
2	Animal biodiversity	2.43	1.15	0.48
3	Crop rotation	2.43	1.15	0.48
4	Grassland área	2.71	0.58	0.21
5	Organic waste management	2.43	1.15	0.48
6	Space valorization	2.14	1.00	0.47
7	Fertilization	2.71	0.58	0.21
8	Manure, slurry and wastewater management residuals	2.71	0.58	0.21
9	Pesticide use	3.00	0.00	0.00
10	Soil resource protection	3.00	0.00	0.00
11	Water resource management	3.00	0.00	0.00
12	Energy efficiency	2.86	0.58	0.20
13	Water quality management	2.57	0.00	0.00
14	Phosphorus balance	2.14	1.00	0.47
15	Specialization	1.71	1.00	0.58
16	Greenhouse gas production	2.57	1.00	0.39
17	Habitat consevation	2.71	0.58	0.21
18	Disposal of milk from animals that received medication	2.43	0.58	0.24
19	Air Quality	2.29	0.58	0.25
20	Carbon sequestration per kg of milk	2.57	1.00	0.39
	Global warming potential *	2.14	2.00	0.93
	Acidification *	2.00	1.53	0.76
	Eutrophication *	2.14	2.00	0.93
	Nitrogen balance *	2.43	1.53	0.63
	Energy balance *	2.43	1.53	0.63
	Animal welfare	**x̄**	**SD**	**CV**
1	Body condition	3.00	0.00	0.00
2	Access to wáter	3.00	0.00	0.00
3	Water quality and water trough cleanliness	2.71	0.58	0.21
4	Dimension of milking stalls and milking parlors	2.86	0.58	0.20
5	Floor condition	3.00	0.00	0.00
6	Cleanliness score of udders	3.00	0.00	0.00
7	Cleanliness score of hindquarters	3.00	0.00	0.00
8	Condition of holding pen floor	3.00	0.00	0.00
9	Presence of shade	3.00	0.00	0.00
10	Teat condition score	3.00	0.00	0.00
11	Absence of cow with tail injuries	2.86	0.58	0.20
12	Locomotion score	3.00	0.00	0.00
13	Use of analgesics and anesthetics in painful procedures	3.00	0.00	0.00
14	Pain management in acute illness	3.00	0.00	0.00
15	Expression of positive social behaviors	3.00	0.00	0.00
16	Flight zone distance	2.71	0.58	0.21

* Indicators that reached a low level of consensus in the Delphi methodology are shown in italics. These indicators were eliminated from the final sustainability list.

Zucali *et al.* (2016), Salinas (2014), and da Silva and Gameiro (2022).

For environmental sustainability, consensus was notably achieved for 20 indicators, including crop rotation, manure management, land fertilization, and energy efficiency (Table 1). Previous studies have highlighted a significant concern regarding the greenhouse gas emissions associated with conventional livestock farming practices, prompting a shift towards mitigating these environmental impacts to foster more sustainable production. Mitigation strategies outlined in literature include minimizing or eliminating tillage practices in favor of alternative land preparation methods for specific crops (Smith *et al.*, 2001; Bacenetti *et al.*, 2015), implementing crop rotation (Cederberg *et al.*, 2005), adopting targeted fertilization techniques (Smith *et al.*, 2007; Eckard *et al.*, 2010), selecting appropriate seed varieties (Evans, 1996), and converting cropland to pasture (Soussana *et al.*, 2009). These indicators also garnered high consensus levels in the current study.

Regarding the social dimension, a substantial consensus was observed for 14 indicators, addressing not only the welfare of workers but also their job satisfaction levels and the potential risk of turnover (Table 1). While the social dimension holds significant importance in sustainability assessments, it tends to be the least defined and often overlooked aspect. Numerous authors emphasize that evaluating social aspects ensures the continuity of livestock farming across generations (da Silva & Gameiro, 2022; Verduna *et al.*, 2020; Broom, 2021; Pérez-Lombardini *et al.*, 2021).

The 16 indicators proposed for evaluating animal welfare through the Delphi method have garnered significant consensus among the participating experts, as outlined in Table 1. This achievement can be partly attributed to the consensus among various authors regarding the importance of animal welfare in assessing sustainability in livestock farming (Broom, 2021; da Silva & Gameiro, 2022; Pérez-Lombardini *et al.*, 2021; Zucali *et al.*, 2016) and the growing significance of animal care in consumers' decisions regarding animal-derived products (Miller *et al.*, 2020). The attention directed towards this issue stems from the shared understanding that enhancing animal welfare contributes to optimal health, ultimately leading to increased profitability in dairy production (Galioto *et al.*, 2017; Broom, 2021; Arvidsson Segerkvist *et al.*, 2020).

Finally, it is crucial to highlight the limited number of studies dedicated to the identification and development of sustainability metrics. Most of the research related to sustainability has evaluated pre-existing methodologies, and the results obtained have varied depending on the methodology used and the areas where they were applied.

Although the number of participants in the methodology was low, and some participants may be more familiar with some particular dimensions of sustainability, the Delphi method did allow to identify pertinent indicators to assess the sustainability of dairy farms across housed and pasture systems. These indicators can be analysed by generating an index for each dimension, in order to balance the differences in the number of indicators included in each of them (environmental, economic, social and animal welfare) and make them comparable. It is expected that this assessment will help to identify both strengths and areas for improvement, thereby improving dairy farming practices in economic, social, environmental, and animal welfare terms.

In conclusion, the use of a top-down approach, as the Delphi methodology, does allow to identify sustainability indicators with a good level of consensus. This set of indicators can be later on used by producers or researchers to assess the sustainability of dairy farms. Feedback from experts is essential for developing reliable assessment tools in many areas, and their participation in this type of methodologies is crucial.

DECLARATION

Declaration of interests

The authors declare that there is no conflict of interest.

Author contributions

MSH: conceptualization, research, analysis, and writing. TT: writing, revising, and editing. All authors contributed to the writing and discussion of the manuscript and approved its final version.

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