BJ O&PM Brazilian Journal of Operations & Production Management

ISSN 2237-8960 (Online)

ABEPRO ASSOCIAÇÃO BRASILEIRA DE ENGENHARIA DE PRODUÇÃO

RESEARCH PAPER

Multi-criteria approach for weights definition of sustainability indicators in the swine supply chain

Silvana Kruger[1] Flavio Trojan[2] Antonio Zanin[1] Mauro Lizot[3] Paulo Afonso[4]

[1]Federal University of Mato Grosso do Sul (UFMS), Pioneiros, MS, Brazil.
[2]Federal University of Technology, Curitiba, PR, Brazil.
[3]Federal University of Parana (UFPR), Curitiba, PR, Brazil.
[4]University of Minho (UM), Braga, Portugal.

How to cite: Kruger, S. D. et al. (2024), "Multi-criteria approach for weights definition of sustainability indicators in the swine supply chain", *Brazilian Journal of Operations and Production Management*, Vol. 21, No. 4, e20242253. https://doi.org/10.14488BJOPM.2253.2024

ABSTRACT

Goal: This study presents a four-steps methodology for the definition of the weights of sustainable indicators in the Swine Supply Chain (SSC) considering the Triple Bottom-Line (TBL) perspective.

Design/Methodology/Approach: The methodology proposed was based on the Bellagio principles that guide the definition of importance levels for TBL criteria. It was applied to the swine supply chain using Saaty's scale and information obtained from managers of two agribusiness companies, adjusted by the AHP method.

Results: The results showed the relevance of an appropriate definition of the preferences of decision-makers to decide on the best actions towards environmental, economic, and social sustainability.

Limitations: The limitations of the proposed model are mainly its subjective nature. Despite being necessary in multi-criteria methods, it could be a limitation if more quantitative indicators are relevant or demanded. Nevertheless, the proposed methodology also provides a quantitative perspective, as a result of using the Saaty scale.

Practical implications: The definition and application of importance levels within a TBL-based model can help managers to prioritize environmental, social, and/or economic dimensions under a large diversity of alternatives toward more sustainable scenarios. The AHP method used in this work is a hierarchy method, particularly appropriate for defining weights that are essentially compensatory by nature.

Originality/value: The correct definition and weight of the different dimensions, sub-dimensions, and respective indicators is currently one relevant gap in the literature, limiting the design and prioritization of corrective actions in each stage of the SSC and in the different dimensions of the TBL.

Keywords: Sustainability Indicators; Triple Bottom-Line; Swine Supply Chain; Multi-Criteria Decision Models.

1 INTRODUCTION

The analysis of supply chains sustainability requires the use of appropriate metrics and models (Kruger & Petri, 2019; Kruger et al., 2022); and can be based on a set of principles as

*This article is from the 29th IJCIEOM—International Joint Conference on Industrial Engineering and Operations Management, Lisbon, 2023. Due to its relevance and contribution to the field, it was invited to be published in the December 2024 Special Issue of the Brazilian Journal of Operations & Production Management.

Financial support: None.
Conflict of interest: The authors have no conflict of interest to declare.
Corresponding author: trojan@utfpr.edu.br
Received: 13 May 2024.
Accepted: 25 September 2024.
Editor: João Reis (Universidade Lusófona); Gaudêncio Freires (Universidade Federal da Bahia); Milton Vieira (Universidade Presbiteriana Mackenzie); Márcio Thomé (PUC-Rio); Luiz Felipe Scavarda (PUC-Rio); Maria Del Mar (Universitat Politècnica de València); Miguel Vieira (Universidade Lusófona).

the Bellagio principles (Pintér et al., 2021). Such metrics and models help with valuable information to turn companies in the supply chain more sustainable (Kruger et al., 2022). Furthermore, they allow a comparative analysis, mostly between the focal company and the upstream and downstream companies (Santiago-Brown et al., 2015). Sustainability models turn possible a better control and regulation of the supply chain activities, reducing the impact of the less sustainable practices (Hardi & Zdan, 1997). However, the models found in the literature present limitations in the process of measuring the different dimensions of sustainability. Particularly, the definition of the weights of the different criteria used to assess the degree of sustainability in supply chains from various perspectives or dimensions, as those proposed by the Triple Bottom Line (TBL) model (Kruger & Petri, 2019; Kruger et al., 2022). Appropriate and robust methodologies are also needed to collect and analyze this data.

The Delphi method has been used often to obtain information from experts in academia and industry with the aim of determining the weights of TBL indicators (Lindeman, 1975; Ahmad & Wong, 2019). This method, based on the knowledge of a group of experts, has proven to be suitable for identifying, selecting and validating indicators, according to Tseng et al. (2015), Henning & Jordaan (2016), Hsu et al. (2017).

Frazzon et al. (2019) emphasize the importance of developing theoretical and practical knowledge of using industry 4.0 techniques in the supply chain. Neri et al. (2021) carried out an extensive literature review on Key Performance Indicators (KPIs) for the evaluation of sustainable practices and identified approximately 70 models based on the KPI Categorization, the Balanced Scorecard (BSC) and the Tipple Bottom-Line model (TBL).

The studies presented in the literature adopt different methodologies based on subjective assessments defined by experts or decision makers. In this context, the Analytic Hierarchy Process (AHP) method is particularly useful because it allows pairwise comparisons and a clearer analysis for these subjective assessments.

For example, Allaoui et al. (2018) used hybrid multi-criteria analysis based on the AHP method and the Ordered Weighted Averaging (OWA) aggregation method to generate a ranking for TBL indicators. The results obtained allowed the development of a multi-objective mathematical model. Indeed, the AHP method can be used to define the weights to support different multi-objective models.

The main difference between the study by Allaoui et al. (2018) and this work is related to the organization of the weight structure for the different dimensions of the TBL indicators. In this case, the AHP method, explained further in this article, was adapted according to equation (8).

In the specific case of the swine production chain, very strict control measures are required to minimize negative environmental, social and economic impacts of the different companies involved (Zanin et al., 2020; Camargo et al., 2018). Furthermore, the companies in the upstream and downstream present very different performance across the three TBL dimensions, with both negative and positive impacts. Thus, sustainability in these production chains needs to be assessed using appropriate indicators for the environmental, social and economic dimensions (TBL) (Malak-Rawlikowska et al., 2021).

Ali et al. (2024) and Lizot et al. (2021) highlight the importance of environmental policies to improve companies' actions for environmental preservation and to reduce hidden costs, such as, energy consumption, pollution and the greenhouse effect. Environmental indicators evaluate energy and environmental practices, soil, water and air. Social indicators are related to social interaction and human capital; and economic indicators include the return on investment and direct labor salaries, among others (Kruger & Petri, 2019). The companies in these supply chains (i.e., the local companies but also those in the upstream and the downstream) need to contribute continuously to higher levels of sustainability (Clift, 2003).

The use of weighted sustainability indicators can help to monitor and evaluate companies' performance, considering the analysis of economic, social and environmental aspects (Narimissa et al., 2020). Thus, such impacts must be measured and analyzed in terms of structured levels of importance, using an appropriate multi-criteria analysis (Dalkey & Helmer, 1963). Furthermore, it can be expected a certain predominance of some dimensions of the TBL among the others, particularly, the economic dimension. However, the social and environmental dimensions are also important. Particularly, because it is common to face a negative social and environmental impact of the swine production chain, affecting families, companies and the society (Camargo et al., 2018).

The 2030 Agenda suggests the integration of sustainable dimensions and the use of aggregate indicators. It allows comparisons among companies and supply chains and the identification of sustainable opportunities to improve processes in the swine production chain (Kruger et al., 2022). The sustainable development and circular economy emphasized the need of a reduction of the impacts of economic activities on the environment (Secco et al., 2020; Olsson & Kruger, 2021).

In this paper, it is proposed a multi-criteria approach to weigh the TBL indicators for swine production, considering the existing literature (Malak-Rawlikowska et al., 2021; Sharma et al., 2017).

The proposed methodology differs from previous works by the definition of weights for sustainability indicators, both from an individual and aggregate perspective, contributing to a better support for decision-making process towards more sustainable supply chains.

This article is structured in five sections. The next section presents the theoretical framework, within the context of the swine supply chain. The third section presents the research methodology and the structure of the proposed model. In the fourth section the results obtained are discussed; and the fifth section summarizes the main conclusions, limitations and opportunities for further work.

2 THEORETICAL FRAMEWORK

Sustainability is about how current decisions can affect future generations (Fleurbaey, 2015). Several studies show concerns about the balance among environmental, social, and economic performance (Vieira et al., 2017; Veleva & Ellenbecker, 2001; Parris & Kates, 2003). The debates to reduce the environmental impacts of economic activities, as well as the implementation of sustainability assessment models, are becoming increasingly important (Pereira et al., 2020). Sustainable development asks for continuous measurement and evaluation of production processes, aiming to guarantee resources for the future (Figge & Hahn, 2004). Evaluating tools are fundamental in sustainability assessment models (Reig-Martínez et al., 2011), supporting the progress toward sustainable production targets (Veleva & Ellenbecker, 2001). The use of measures to evaluate weights allows the identification of importance levels, as well as the design of strategies to reach the objectives (Melnyk et al., 2014). Sustainability indicators must be (i) measurable, (ii) relevant, (iii) understandable, (iv) reliable, (v) obtainable, and (iv) manageable, to allow organizations to manage and make decisions in favor of sustainable development (Feng & Joung, 2009). The Bellagio Principles were formulated in Bellagio, Italy, in 1996, by an international group of researchers and evaluation specialists from the International Institute for Sustainable Development (IISD, 1996), to highlight the perception of the main aspects related to the evaluation of sustainable development (Pintér et al., 2012, Hardi & Zdan, 1997). Table 1 presents the principles and characteristics of sustainability assessment models, defined as Bellagio's Principles (Pintér et al., 2012, Hardi & Zdan, 1997).

Table 1 - Bellagio's principles of the assessment of sustainable development

Principle 1: Guiding vision	It guides the evaluation of the sustainability of the biosphere. It is also about a vision of the direction and desirable changes according to different scenarios.
Principle 2: Essential considerations	It focus on the social, economic, and environmental aspects and their interactions, including environmental governance; dynamics between current trends, and the possibilities of change.
Principle 3: Appropriate scope	Adopting an adequate time horizon and geographic scope.
Principle 4: Structure and indicators	Building conceptual frameworks considering the relevant characteristics and indicators; standardized measurement methods; the comparison between the obtained values and the defined targets.
Principle 5: Transparency	Importance of adequate and accessible data, indicators and results; which is used to explain the choices, assumptions and uncertainty of the evaluation; based on clear and known methods and data sources; disclosing funding sources and conflicts of interest.
Principle 6: Effective communication	The use of effective communication, using clear and simple language and the avialble data; presenting information clearly and objectively; using visual tools to help analysis and interpretation.
Principle 7: Participation	Reinforcement of legitimacy, finding appropriate ways to reflect public views, active leadership; and engaging the users of the assessment.
Principle 8: Continuity and capacity	It requires repeated measurement; responsiveness to change; investment to develop and maintain adequate capacity; continuous learning and improvement.

Source: Adapted from Pintér et al. (2012); Hardi & Zdan (1997).

Table 1 details Bellagio's principles to design a more sustainable performance model, based on indicators and metrics towards higher levels of sustainability (Pintér et al., 2012, Hardi & Zdan, 1997). In the assessment of the sustainability of production systems, the indicators must allow the analysis of economic, environmental and social dimensions (Santiago-Brown et al., 2015.

Furthermore, it must be done from a continuous improvement perspective, extended throughout the entire production chain (Kruger et al., 2022; Zanin et al., 2020).

The objectives of the 2030 Agenda indicate that there is a need of better measurement models based on the TBL perspectives (Sharma et al., 2017). Considering the impacts of swine production on the environment, it becomes relevant to use metrics from the TBL dimensions (Kruger & Petri, 2019, Zanin et al., 2020). Models with a balanced set of TBL variables, can contribute to a more sustainable development of production chains (Narimissa et al., 2020).

An integrated management of production chains is important for respecting environmental limits and for reducing the consumption of natural resources (Uemura et al., 2022). Other challenges in sustainable swine production are related to the use of advanced production technologies and artificial intelligence (Mahfuz et al., 2022). The use of TBL indicators can benefit sustainability objectives (Liu & Xiao, 2016). Several studies carried out in different regions, such as Brazil (Kruger et al., 2022), Zanin et al., 2020), Sweden (Zira et al., 2020, Zira et al., 2021), China (Liu & Xiao, 2016), Colombia (Trujillo-Díaz et al., 2021), Vietnam (Nguyen et al., 2020) and Uganda (Ouma et al., 2017), indicate the relevance of using TBL models to assess the sustainability of pig production.

Malak-Rawlikowska et al. (2021), studied the economic sustainability of pig farms, concluding that full-cycle farms can be economically more sustainable than specialized ones. Trujillo-Díaz et al. (2021) highlighted a deficit of technology, infrastructure, economic incentives and public policies in the Colombian swine industry.

The study of Zira et al. (2020) presented a research that assess the sustainability of organic products and Zira et al. (2021) focus on Life Cycle Assessment (LCA) of swine supply chains considering four production stages: farm and feed production, slaughter, wholesale/retail and consumption, analysed from the three TBL dimensions. It contributes to identify the trade-offs among the three pillars of sustainability. Ouma et al. (2017) carried out an assessment of the pig supply chain including social risks at the farm level and detected several opportunities for improvement in sustainable production. Liu and Xiao (2016) studied the treatment and recycling of effluents and residues in manure and feed, developing a stochastic optimization model for the swine production supply chain, allowing circular economy with efficiency reuse of resources.

In the context of swine farming, there is a lack of studies that address the assessment of the TBL dimensions and indicators (Kruger et al., 2022; Zira et al., 2021), which is what is proposed in this research work.

3. METHODOLOGY

Following the Bellagio's principles (Pintér et al., 2021), TBL dimensions become fundamental in sustainability assessment (Santiago-Brown et al., 2015). The definition of importance level of each indicator represents an important step in this process (Zanin et al., 2020). In Figure 1 it is presented the structure of the proposed methodology, adapted from Kruger et al. (2022).

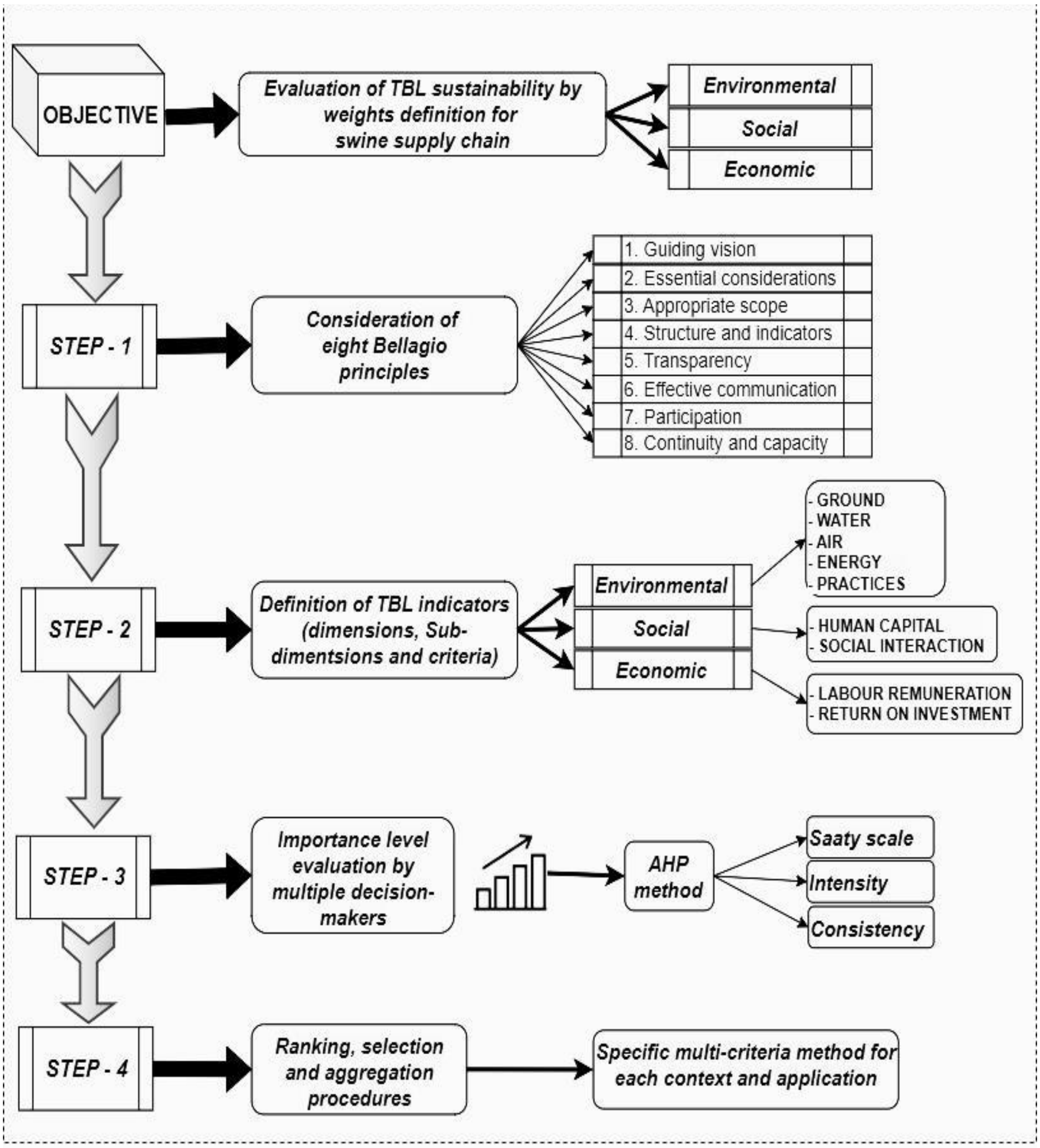

Figure 1 – Proposed methodology

The proposed methodology is structured in 4 main steps.

Step 1 – Consideration of TBL dimensions, sub-dimensions, and indicators for the swine supply chain and based on Bellagio's principles (Table 1).

Step 2 - Sorting of TBL dimensions, sub-dimensions, and indicators.

Step 3 - Definition of weights by the AHP (Analytic Hierarchy Process) method.

Step 4 - Aggregated weighting procedure to select from the potential alternatives to promote sustainable actions in the swine supply chain.

In the step 2, the indicators are compared by experts in a pairwise evaluation and grouped to define the importance levels for each criterion, using the AHP method.

The AHP method uses Saaty´s scale (Saaty, 2008), with values of importance for each comparison (1 to 9), and inversely (1⁄1 to 1⁄9).

In this work, the AHP method was adapted to provide a percentage order to weigh the criteria. This procedure allows to define the importance level of each criterion in the swine supply chain context.

A summarized matrix of the AHP method is presented in Table 2.

Table 2 - Sample matrix of AHP method

Saaty' scale	
1/9 =	Absolutely worst than
1/7 =	Much worst than
1/5 =	Worst than
1/3 =	A little worst than
1 =	Same importance
3 =	A little better than
5 =	Better than
7 =	Much better than
9 =	Absolutely better than

Evaluation matrix of AHP to criteria weights								
X	C1	C2	C3	C4	C5	C6	Eigen vector	Weight %
C1	1.00	v_{12}	v_{13}	v_{14}	v_{15}	v_{16}	Eq(1)	Eq(2)
C2	$1/v_{12}$	1.00	v_{23}	v_{24}	v_{25}	v_{26}	Eq(1)	Eq(2)
C3	$1/v_{13}$	$1/v_{23}$	1.00	v_{34}	v_{35}	v_{36}	Eq(1)	Eq(2)
C4	$1/v_{14}$	$1/v_{24}$	$1/v_{34}$	1.00	v_{45}	v_{46}	Eq(1)	Eq(2)
C5	$1/v_{15}$	$1/v_{25}$	$1/v_{35}$	$1/v_{45}$	1.00	v_{56}	Eq(1)	Eq(2)
C6	$1/v_{16}$	$1/v_{26}$	$1/v_{36}$	$1/v_{46}$	$1/v_{56}$	1.00	Eq(1)	Eq(2)
∑	S1	S2	S3	S4	S5	S6	SEigen	Eq(2)
λmax							Eq(3)	
CI = Consistency Index							Eq(4)	
CR = Consistency Ratio							Eq(5)	≤ 0.10

Random consistency index RI									
1	2	3	4	5	6	7	8	9	10
0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Saaty's (2008) Eigenvector vi is calculated by the geometric mean of the values, equation (1), the weights by normalized values, equation (2), and the Consistency Ratio (CR), equation (5), is calculated by the ratio between the Consistency Index (CI), equations (3) and (4), and the random consistency Index (RI), Table 2.

$$v_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{\frac{1}{2}} \quad (1)$$

The weight vector of criteria wi is calculated as a percentage, equation (2).

$$w_{i(\%)} = {v_i}/{\sum_{i=1}^{n} v_i}$$, being

$$\sum_{i=1}^{n} w_{i(\%)} = 1 \quad (2)$$

and

$$\alpha_{max} = \sum_{i=1}^{n} c_{ij}.w_i \quad (3)$$

The Consistency Index (CI) is calculated based on equation (4).

$$CI = \frac{\alpha_{max-n}}{n-1} \quad (4)$$

The Consistency Ratio (CR) is considered the principal indicator of consistency and it is calculated based on the eigenvalue α_max and the number of elements (n), equation (5).

$$CR = \frac{CI}{RI} \quad (5)$$

Saaty (2008) calculated a Random Index (RI) which is the average of (CI) over random entries of the same order - in this case, those presented in Table 2. Table 3 presents the structure of dimensions, sub-dimensions, and indicators used in this study.

Table 3 - Criteria for the analysis from the TBL perspective based on Bellagio's principles

Dimensions	Sub-dimensions	Indicators	Weight procedures
Environmental	GROUND	- Soil Physical-Chemical Analysis - Soil conservation practices - Land occupation	Pairwise comparison between criteria
	WATER	- Source animal consumption - Facilities distance from sources - Conscious use of water	
	AIR	- Greenhouse gas emissions - Air quality	
	ENERGY	- Total energy use - Waste treatment	
	PRACTICES	- Regularization - Animal Welfare	
Social	HUMAN CAPITAL	- Satisfaction with the countryside	Pairwise comparison between criteria
		- Work System	
		- Personal training	
	SOCIAL INTERACTION	- Quality of life	
		- Social participation	
		- Social programs	
		- Perception of environmental impacts	
		- Providers of social interaction	
Economic	LABOR REMUNERATION	- Labor remuneration value	
	RETURN ON INVESTMENT	- Return per housed pig	
		- Net profit	
		- Payback time	

Source: Adapted from Zanin et al. (2020).

4. ANALYSIS OF RESULTS

The decision-makers invited to make the evaluation are managers of two companies of the swine supply chain in the south of Brazil.

Company 1 and Company 2 work under the integration system with the company BRF (a Brazilian multinational food company), in the termination phase. The company receives the piglets, feed, medicines, and technical assistance from the focal company that controls the process. Both companies provide the needed facilities, electricity, and direct labor. The local company pays a fee per animal housed, based on feed conversion. The feeding system is automatic and has scheduled times, meaning that no labor is required for this activity.

Company 1 has two workers and facilities for housing 1,200 animals; integrating also an aviary. Company 2 has also two workers in two facilities, and houses more animals (i.e., 1,998 animals). It uses a solar energy system and also produces milk.

Both companies have manure pits, used as organic fertilizer in pastures and grain production for cattle.

The evaluations were made by pair-to-pair comparisons for each indicator, considering the categories defined in step 3 of the proposed methodology. This procedure was repeated for company 2 for all indicators categorized in the Environmental dimension and respective sub-dimensions, as shown in Table 4.

Table 4 - Weights for TBL environmental indicators of sub-dimensions

Weights definition for soil					
X	Soil Physical-Chemical Analysis	Soil conservation practices	Land occupation	Eigen Vector	**Weights %**
Soil Physical-Chemical Analysis	1.00	9.00	7.00	3.9	**78.5%**
Soil conservation practices	0.11	1.00	0.33	0.3	**6.6%**
Land occupation	0.14	3.00	1.00	0.7	**14.9%**
∑	1.25	13.00	8.33	5.06	**100%**
	λmax			3.08	
	CI = Consistency Index			0.04	
	CR = Consistency Ratio			0.069	≤ 0.10

Weights definition for water					
X	Source animal consumption	Facilities distance from sources	Conscious use of water	Eigen Vector	**Weights %**
Source animal consumption	1.00	7.00	9.00	3.9	**78.5%**
Facilities distance from sources	0.14	1.00	3.00	0.7	**14.9%**
Conscious use of water	0.11	0.33	1.00	0.3	**6.6%**
∑	1.25	8.33	13.00	5.06	**100.0%**
	λmax			3.08	
	CI = Consistency Index			0.04	
	CR = Consistency Ratio			0.069	≤ 0.10

Weights definition for air				
X	Greenhouse gas emissions	Air quality	Eigen Vector	**Weights %**
Greenhouse gas emissions	1.00	9.00	3.00	**90.0%**
Air quality	0.11	1.00	0.33	**10.0%**
∑	1.11	10.00	3.33	**100.0%**
	λmax		2.00	
	CR = Consistency Ratio		0.00	≤ 0.10

Weights definition for energy				
X	Total energy use	Waste treatment	Eigen Vector	**Weights %**
Total energy use	1.00	9.00	3.00	**90.0%**
Waste treatment	0.11	1.00	0.33	**10.0%**
∑	1.11	10.00	3.33	**100.0%**
	λmax		2.00	
	CR = Consistency Ratio		0.00	≤ 0.10

Weights for soil conservation practices				
X	Regularization	Animal welfare	Eigen Vector	**Weights %**
Regularization	1.00	7.00	2.64	**87.5%**
Animal welfare	0.14	1.00	0.37	**12.5%**
∑	1.14	8.00	3.02	**100.0%**
	λmax		2.00	
	CI = Consistency Index		0.00	
	CR = Consistency Ratio		0.00	≤ 0.10

Tables 4 to 6 summarize the evaluations made for Company 1 and all indicators. The results for Company 2 are summarized in Tables 7 and 8.

The decision-makers preferences were elicited considering Saaty' scale for environmental indicators and sub-dimensions, and the AHP method calculation. The preferences about Social Indicators were considered according to the respective indicators, presented in Table 5.

Table 5 - Weights for TBL social indicators of sub-dimensions

Table 5 - Weights for TBL social indicators of sub-dimensions

Weights definition for human capital					
X	Satisfaction with countryside	Work system	Personal training	Eigen Vector	**Weights %**
Satisfaction with countryside	1.00	7.00	9.00	3.98	**78.5%**
Work system	0.14	1.00	3.00	0.75	**14.9%**
Personal training	0.11	0.33	1.00	0.33	**6.6%**
∑	1.25	8.33	13.00	5.07	**100.0%**
	λmax			3.08	
	CI = Consistency Index			0.04	
	CR = Consistency Ratio			0.07	≤ 0.10

Weights definition for social interaction							
X	Quality of life	Social participation	Social programs	Perception on env. impacts	Providers social interaction	Eigen Vector	**Weights %**
Quality of life	1.00	5.00	3.00	3.00	3.00	2.67	**46.0%**
Social participation	0.20	1.00	1.00	1.00	1.00	0.72	**12.5%**
Social programs	0.33	1.00	1.00	1.00	1.00	0.80	**13.8%**
Perception on env. impacts	0.33	1.00	1.00	1.00	1.00	0.80	**13.8%**
Providers social interaction	0.33	1.00	1.00	1.00	1.00	0.80	**13.8%**
∑	2.20	9.00	7.00	7.00	7.00	5.80	**100.0%**
				λmax		5.04	
				CI = Consistency Index		0.01	
				CR = Consistency Ratio		0.01	≤ 0.10

Table 6 presents the definition of weights for Economic indicators and respective sub-dimensions, also considering Saaty's scale and the AHP method.

Table 6 - Weights for TBL economic indicators of sub-dimensions

Weights definition for labor remuneration			
X	Labor remuneration value	Eigen Vector	**Weights %**
Labor remuneration value	1.00	1.00	**100.0%**
∑	1.00	1.00	**100.0%**
	λmax	0.00	
	CI = Consistency Index	0.00	
	CR = Consistency Ratio	0.00	≤ 0.10

Weights definition for return on investment					
X	Return per housed pig	Net profit	Payback time	Eigen Vector	**Weights %**
Return per housed pig	1.00	7.00	5.00	3.27	**73.1%**
Net profit	0.14	1.00	0.33	0.36	**8.1%**
Payback time	0.20	3.00	1.00	0.84	**18.8%**
∑	1.34	11.00	6.33	4.48	**100.0%**
	λmax			3.06	
	CI = Consistency Index			0.03	
	CR = Consistency Ratio			0.06	≤ 0.10

The procedure used to calculate the weights for sub-dimensions and dimensions is presented in equation (6).

$$w_{med(\%)} = median(v_i) \quad (6)$$

Subsequently, a normalized procedure was performed following equation (7).

$$w_{i(\%)} = \frac{w_{med(\%)}}{\sum_{i=1}^{n} v_i}$$

$$\sum_{i=1}^{n} w_{i(\%)} = 1 \quad (7)$$

The global results of this step are summarized in Tables 7 (Company 1) and 8 (Company 2) allowing performing other procedures such as ranking, sorting, and the selection of potential alternatives to improve sustainability in the swine supply chain.

The weights calculation was based on the Equation (8), where the individual weights of indicators, sub-dimensions and dimensions were multiplied, and considering the sum of weights equal to one.

$$w_i = [1]w_{i(AHP)} * [2]w_{i(subD)} * [3]w_{i(D)} \quad (8)$$

Table 7 - Weights definition for TBL indicators - Company 1

Criteria (indicators)	**Weights AHP [1]**	**Sub-dimension**	**Weights sub-dim. [2]**	**Dimensions**	**Weights dimensions [3]**	**Final W [1]*[2]*[3]**
Soil physical chemical analysis	78.54%	Ground	8.30%	ENVIRON-MENTAL	21.80%	1.42%
Soil conservation practices	6.58%					0.12%
Land occupation	14.88%					0.27%
Source for animal consumption	78.54%	Water	8.30%			1.42%
Facilities distance from sources	14.88%					0.27%
Conscious use of water	6.58%					0.12%
Greenhouse gas emissions	90.00%	Air	27.80%			5.45%
Air quality	10.00%					0.61%
Total energy use	90.00%	Energy	27.80%			5.45%
Waste treatment	10.00%					0.61%
Regularization	87.50%	Practices	27.80%			5.30%

Animal welfare	12.50%					0.76%
Satisfaction with countryside	78.54%	Human	51.80%	SOCIAL	39.10%	15.91%
Work system	14.88%					3.01%
Personal training	6.58%					1.33%
Quality of life	45.99%	Capital	48.20%			8.67%
Social participation	12.50%					2.35%
Social programs	13.84%					2.61%
Perception on environ. impacts	13.84%					2.61%
Providers of social interaction	13.84%					2.61%
Labor remuneration value	100.00%	Labor	52.10%	ECONOMIC	39.10%	20.37%
Return per housed pig	73.06%	Return	47.90%			13.68%
Net profit	8.10%					1.52%
Payback time	18.84%					3.53%
SUM					100.00%	100.00%

Table 8 - Weights definition for TBL indicators - Company 2

Criteria (indicators)	Weights AHP [1]	Sub-dimension	Weights sub-dim. [2]	Dimensions	Weights dimensions [3]	Final W [1]*[2]*[3]
Soil physical chemical analysis	48.69%	Ground	20.90%	**ENVIRON-MENTAL**	**19.40%**	1.97%
Soil conservation practices	7.78%					0.32%
Land occupation	43.53%					1.76%
Source for animal consumption	78.54%	Water	7.10%			1.08%
Facilities distance from sources	14.88%					0.20%
Conscious use of water	6.58%					0.09%
Greenhouse gas emissions	87.50%	Air	24.00%			4.07%
Air quality	12.50%					0.58%
Total energy use	87.50%	Energy	24.00%			4.07%
Waste treatment	12.50%					0.58%
Regularization	87.50%	Practices	24.00%			4.07%
Animal welfare	12.50%					0.58%
Satisfaction with countryside	42.86%	Human	66.45%	**SOCIAL**	**40.30%**	11.48%
Work system	14.29%					3.83%
Personal training	42.86%					11.48%
Quality of life	21.64%	Capital	33.55%			2.93%
Social participation	21.64%					2.93%
Social programs	10.11%					1.37%
Perception on environ. impacts	4.79%					0.65%

Providers of social interaction	41.83%					5.66%
Labor remuneration value	100.00%	Labor	81.20%	ECONOMIC	**40.30%**	32.72%
Return per housed pig	79.86%	Return	18.80%			6.05%
Net profit	9.65%					0.73%
Payback time	10.49%					0.79%
SUM					100.00%	100.00%

It was possible to recognize that in terms of environmental aspects, the decision-makers agreed that weights for Greenhouse gas emissions (maximum 5.45%), Total energy use (maximum 5.45%), and Regularization (maximum 5.30%) are the most important criteria to guide environmental actions in their businesses. In the Social dimension, the Satisfaction with the countryside (maximum 15.91%) was considered the most important criterion. In the social dimension, some criteria have had perceptions changed by decision-makers, such as Personal training, Quality of life, and Providers, in which one decision-maker preferred one indicator instead of another and vice-versa. In the Economic dimension, the Labor remuneration value (maximum 32.72%) and Return per housed pig (maximum 13.68%) were selected as the most important criteria.

Table 9 - Weights summary for TBL indicators (company 1 vs company 2)

Dimensions	Criteria (indicators)	Weights indicators company 1	Weights indicators company 2	Weights variation (comp1–comp2)
ENVIRON-MENTAL	Soil physical chemical analysis	1.42%	1.97%	-0.55%
	Soil conservation practices	0.12%	0.32%	-0.20%
	Land occupation	0.27%	1.76%	-1.49%
	Source for animal consumption	1.42%	1.08%	0.34%
	Facilities distance from sources	0.27%	0.20%	0.07%
	Conscious use of water	0.12%	0.09%	0.03%
	Greenhouse gas emissions	5.45%	4.07%	1.38%
	Air quality	0.61%	0.58%	0.03%
	Total energy use	5.45%	4.07%	1.38%
	Waste treatment	0.61%	0.58%	0.03%
	Regularization	5.30%	4.07%	1.23%
	Animal welfare	0.76%	0.58%	0.18%
SOCIAL	Satisfaction with countryside	15.91%	11.48%	4.43%
	Work system	3.01%	3.83%	-0.82%
	Personal training	1.33%	11.48%	-10.15%
	Quality of life	8.67%	2.93%	5.74%
	Social participation	2.35%	2.93%	-0.58%
	Social programs	2.61%	1.37%	1.24%
	Perception of environ. impacts	2.61%	0.65%	1.96%
	Providers of social interaction	2.61%	5.66%	-3.05%
ECONOMIC	Labor remuneration value	20.37%	32.72%	-12.35%
	Return per housed pig	13.68%	6.05%	7.63%

	Net profit	1.52%	0.73%	0.79%
	Payback time	3.53%	0.79%	2.74%
SUM	SUM	100.00%	100.00%	0.00%

The most relevant variation in the definition of the weights for the two studied companies was the Personal training (with a variation of -10.15%) and Labor remuneration value (with a variation of -12.35%) showing different perceptions and preferences from the decision-makers (companies' managers).

Based on the results presented in Tables 7 to 9 it is possible to recognize the structure of TBL weights, built using managers' opinions. The weights defined for each indicator are presented in the last column of the different Tables.

The global median and by indicator presented in each dimension and sub-dimension was calculated considering the sub-dimension categorization and weights. Finally, the weights for the indicators were normalized considering these three aspects concomitantly by the weight multiplication (equation 6).

It was observed in the weight analysis that Company 1 contributes with 21.80% and Company 2 with 19.40% to the environmental dimension; Company 1 with 39.10% and Company 2 with 40.30% to the economic and social dimensions, respectively. This is based on the perception of the interviewed managers and can be adjusted in new cases and situations, or/and using new criteria for evaluating the different metrics, making it possible to adapt the model to different companies, industries, regions and countries. In addition, it is possible to update the measures with a higher frequency, depending on each particular case.

This methodology provides a structuration of the importance levels of TBL indicators and respective dimensions.

The results show advances concerning to previous research (e.g., Malak-Rawlikowska et al., 2021) namely, about social aspects. Indeed, our study also adds social and environmental aspects, answering to the claim for a more complete view and application of the TBL perspective.

The methodology presented here and the results obtained can be compared with previous studies (e.g., Liu & Xiao, 2016; Trujillo-Díaz et al., 2021; Ouma, 2017), also focused on the evaluation of the swine production supply chain. This model can also be used to evaluate sustainability at the farm level.

Furthermore, it is aligned with the work of Liu & Xiao (2016) and Kruger et al. (2022), contributing to the discussion on the importance of using evaluation models and metrics in TBL approaches.

5. CONCLUSIONS

It is proposed here a methodology to weight TBL indicators, sub-dimensions, and dimensions for the swine industry, using an adapted procedure in the AHP method to define the importance of the different dimensions, sub-dimensions and indicators.

Sustainable decisions ask to consider the different dimensions of the problem and their respective levels of importance, taking into consideration the opinions of experts and managers. Therefore, this work presents a model that incorporates these two aspects in the definition of structured weights for the swine production chain.

So, the proposed model incorporates both the expert and managers opinions and the different dimensions of the TBL in the definition of the structured weights for sustainability indicators in the swine supply chain.

The proposed methodology is aligned with the Bellagio's principles (Pintér et al., 2021; Hard & Zdan, 1997) which highlight the importance of a guiding vision, an appropriate set of assumptions and scope, a set of structured indicators, full transparency of the process, an effective communication, stakeholder's participation, etc., providing better conditions for more sustainable decisions.

The results showed the relationships among indicators, sub-dimensions, and global dimensions from the different TBL dimensions. Furthermore, the decision-making might be better supported if all these aspects are presented numerically and eventually through visual models.

Nevertheless, some limitations should be highlighted, particularly those related to compensatory aspects. In multi-criteria approaches, problems with non-compensatory, compensatory, and miscellaneous characteristics can be found. The AHP method was used in the proposed model for weights definition with a compensatory nature.

Further works may consider multi-criteria methods combined with AHP, considering non-compensatory and compensatory aspects. Future works, could also incorporate the weights to define different multi-criteria approaches like ranking, sorting, or selection of alternatives for sustainable development.

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Author contributions: Silvana D. Kruger and Flavio Trojan; Methodology: Silvana D. Kruger and Flavio Trojan; Validation: Antonio Zanin, Mauro Lizot, Paulo Afonso and Flavio Trojan; Formal analysis: Antonio Zanin, Mauro Lizot and Paulo Afonso; Investigation: Silvana D. Kruger and Flavio Trojan; Resources: Antonio Zanin, Mauro Lizot and Paulo Afonso; Data curation: Silvana D. Kruger and Flavio Trojan; Writing - original draft preparation: Silvana D. Kruger and Flavio Trojan; Writing - review and editing: Silvana D. Kruger, Flavio Trojan, Antonio Zanin, Mauro Lizot and Paulo Afonso; Visualization: Antonio Zanin, Mauro Lizot, and Paulo Afonso; Supervision: Antonio Zanin, Flavio Trojan, and Paulo Afonso; Project administration: Flavio Trojan and Paulo Afonso. All authors have read and agreed to the published version of the manuscript.