Revista Brasileira de Zootecnia

Sustainability index approach of the Brazilian Pampa biome

Luiz Antonio Vieira Queiroz Filho[1] (iD), Tamara Esteves de Oliveira[1] (iD), Daniele Zago[1] (iD), Claus Köbrich[2] (iD), Cimélio Bayer[3,4] (iD), Júlio Otávio Jardim Barcellos[1]* (iD)

[1] Universidade Federal do Rio Grande do Sul, Departamento de Zootecnia, NESPro, Porto Alegre, RS, Brasil.
[2] University of Chile, Faculty of Veterinary and Animal Sciences, Department of Livestock Production, Santiago, Chile.
[3] Universidade Federal do Rio Grande do Sul, Departamento de Solos, Porto Alegre, RS, Brasil.
[4] INCT - Agricultura de Baixa Emissão de Carbono, Porto Alegre, RS, Brasil.

ABSTRACT - The aim of the study was to develop an index to measure sustainability in production systems. This sustainability index (iSus) was developed to be adhered to the Brazilian Pampa biome based on experts' perceptions, in five regions of the Brazilian Pampa biome: Western border, Northwestern border, Campanha, Central, and South. The Sustainability Assessment of Food and Agriculture Systems guidelines, developed by the Food and Agriculture Organization, were used as reference for the indicators that formed the iSus. After selecting the indicators, a predefined list of experts was consulted to rank their priorities according to the analytic hierarchy process methodology. An electronic form was developed and sent to experts from each region assess the priorities of the dimensions, themes, and indicators. The selected dimensions did not differ, demonstrating that in the experts' perception, no dimension has priority. Among the themes, investment (economic dimension), human health and safety (social dimension), and land and water (environmental dimension), were prioritized within the dimensions. In the analysis of indicators, there were no differences between the experts' perceptions and the regions analyzed. Indicators could be classified into groups of high, medium, and low priority. Water management, safety and health training, and net revenue were ranked as the highest priorities by the experts. The prioritization, together with the incorporation of an iSus, can contribute to broad actions to enhance sustainability in agricultural production systems. The use of the index will allow the measurement and identification of the basic premises of sustainability could be measured and identified.

Keywords: ecological restoration, livestock, sustainability

1. Introduction

Increasing food production while reducing the environmental impacts of agricultural activities will be the major challenges for farmers and the research community in the coming decades (Calicioglu et al., 2019). Farming processes that rely on use the current production models, based on intensive use of inputs and monocultures, will require changes to build more sustainable production models (Carvalho et al., 2018).

2

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

The challenge of enhancing the sustainability of production systems requires a comprehensive understanding of their fundamental principles, which extend beyond the environmental dimension. As early as 1999, Gibon had already postulated that sustainability should be addressed through economic, social, and environmental perspectives (Gibon et al., 1999). For example, the efficient use of energy derived from solar radiation has been identified as a key factor in sustainable agriculture (Heitschmidt et al., 1996).

According to Oltjen and Beckett (1996), sustainability lies in the use of animal products that are inedible to humans. In sustainable intensification, principles and practices aim to increase the efficiency of natural resources are postulated, either by increasing synergies among different farming processes or by optimizing the use of these resources through reduced losses (Garnett et al., 2013; Godfray, 2015; Adegbeye et al., 2020).

In Brazil, with 193,93 million head of cattle and 160,54 million hectares of pastures, beef production is predominantly pastoral, only 19.86% of slaughtered animals originating from feedlots (ABIEC, 2023). This characteristic of beef cattle production allows pastures to mitigate the effects of GHG emissions from agricultural activities (Vasconcelos et al., 2018). The Brazilian Pampa biome (BPB) is different from others because of its climate, which determines the abundance of fauna and flora, and livestock plays an important role in the exploitation of its resources. Several studies have highlighted the relevance of this region's productive potential and ecosystem services (Pillar et al., 2015; Carvalho et al., 2019). According to MapBiomas (2025), among Brazil's biomes, the Pampa has undergone the highest proportion of degradation relative to its total area. Between 1985 and 2020, approximately 21.04% of its native vegetation cover was lost, leading primarily to the degradation of native grasslands, climate imbalances, and biodiversity loss. Since the 2000s, the impacts of expanding crop areas over livestock areas and their effects on the beef supply chain have been discussed (Barcellos et al., 2004). Many other themes have been studied in the BPB (Marques et al., 2011; Ruviaro et al., 2015; Ruviaro et al., 2016; Freitas et al., 2019; Lampert et al., 2020). However, studies analyzing the three dimensions of sustainability in farming systems of the BPB are scarce.

Sustainability assessment tools have been developed by different global initiatives for supply chains. Among them, the Sustainability Assessment of Food and Agriculture Systems (SAFA) guidelines (FAO, 2013, 2014) establish indicators to measure sustainability at different levels of the agricultural supply chains. Although their full application creates difficulties for sustainability assessments in production systems, developers encourage adaptations to enhance accuracy and robustness in the evaluations. Similarly, the analytic hierarchy process (Saaty, 1990) allows the perception of experts to be identified and quantified. Therefore, we hypothesize that a simple, practical, and robust sustainability indicator can effectively assess and differentiate levels of sustainability across various beef cattle production systems. The main objective of this study was to establish a simple and practical index, capable of measuring and evaluating sustainability in beef cattle systems, with low adoption costs.

2. Material and methods

The study was carried out in the area covering the Brazilian Pampa biome (BPB) in Rio Grande do Sul, Brazil. Five regions (Figure 1) representing this biome were considered: Western border (WB), Northwestern border (NB), Campanha (C), Central (Ce), and South (S).

The BPB occupies the southern half of Rio Grande do Sul, with an area of approximately 176,000 km^2, which is equivalent in size to Uruguay. This biome extends to the savannas, where the relief is low and herbaceous species are predominant (IBGE, 2004a; Boldrini et al., 2015). Natural grasslands within this biome support livestock activities, despite the strong participation of agriculture, with irrigated rice farming as a consolidated agricultural activity (Reis and Saibro, 2004). Moreover, beef cattle production and natural grasslands comprise the sociocultural identity of this region and are an embodiment of the Gaúcho (Brum Neto, 2008).
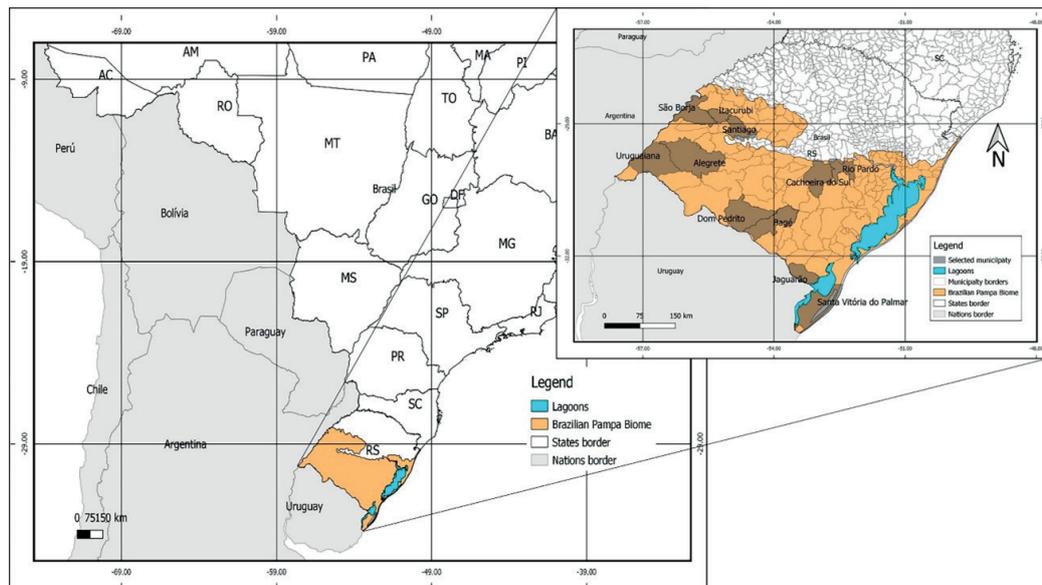
3

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

Figure 1 - Brazilian Pampa biome and the municipalities of the five regions considered for this study.

Municipalities were selected in the study area based on the number of rural establishments (Table 1), cattle herds (Table 2), and land utilization (Table 3). Owing to the geographic dispersion of these regions, soil differences within the BPB were also considered (Streck et al., 2008). The selected municipalities to represent these regions were Uruguaiana and Alegrete (WB), São Borja, Itacurubi, and Santiago (NB), Bagé and Dom Pedrito (C), Santa Vitória do Palmar and Jaguarão (S), and Rio Pardo and Cachoeira do Sul (Ce).

Table 1 - Characterization of rural establishments for 2017 and stratified participation of establishments according to area, for the Rio Grande do Sul state, Pampa biome municipalities, selected municipalities and analyzed regions total

| | Rural establishments (2017) | | | |
| | Total area | < 500 ha | 500-1000 ha | > 1000 ha |
	Hectares (1000)	Participation (%)		
Rio Grande do Sul	21,684.6	51.4	15.3	33.3
Pampa biome municipalities	15,910.5	46.8	17.6	35.6
Analyzed regions total	3,553.7	26.4	20.8	52.8
Western border	1,245.8	23.1	21.1	55.7
Alegrete	726.4	27.2	22.0	50.8
Uruguaiana	519.5	17.4	20.0	62.6
Campanha	801.2	20.1	21.2	58.6
Bagé	353.5	23.3	22.9	53.8
Dom Pedrito	447.7	17.6	19.9	62.4
South	446.4	24.5	18.7	56.8
Santa Vitória do Palmar	284.6	21.4	17.9	60.7
Jaguarão	161.8	29.9	20.1	50.0
Central	483.5	43.0	20.0	36.9
Rio Pardo	176.8	47.6	16.5	35.9
Cachoeira do Sul	306.7	40.4	22.1	37.5
Northwestern border	576.8	29.9	21.7	48.4
São Borja	293.0	20.7	21.3	58.0
Itacurubi	85.3	36.6	24.6	38.8
Santiago	198.5	40.7	20.9	38.4

Source: Adapted from IBGE (2006, 2017) (Censo Agropecuário 2006; Censo Agropecuário 2017).

4

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

Table 2 - Cattle herd characterization for 2017, and cattle herd evolution in the 2006-2017 period for the Rio Grande do Sul state, Pampa Biome municipalities, selected municipalities and analyzed regions total

	Cattle herd (2017)	Evolution (2006-2017)
	Heads (1000 heads)	Percentual (%)
Rio Grande do Sul	11,456.9	1.1
Pampa biome municipalities	9,063.4	1.4
Analyzed regions	3,669.2	0.8
Western border	900.2	23.9
Alegrete	576.7	17.1
Uruguaiana	323.5	38.2
Campanha	542.2	4.7
Bagé	243.1	17.0
Dom Pedrito	299.2	−3.5
South	232.7	−16.5
Santa Vitória do Palmar	141.4	−17.1
Jaguarão	91.4	−15.7
Central	227.1	−18.8
Rio Pardo	89.8	−21.7
Cachoeira do Sul	137.2	−16.9
Northwestern border	382.5	5.4
São Borja	137.9	6.0
Itacurubi	92.9	4.5
Santiago	151.6	−11.9

Source: Adapted from IBGE (2006, 2017) (Censo Agropecuário 2006; Censo Agropecuário 2017).

Table 3 - Land use in temporary crop, natural grassland and cultivated pastures in 2017 and the evolution of these areas in the 2006-2017 period, for the Rio Grande do Sul state, Pampa Biome municipalities, selected municipalities and analyzed regions total

	Land use (2017)			Evolution (2006-2017)		
	Temporary crop	Natural grassland	Cultivated pasture	Temporary crop	Natural grassland	Cultivated pasture
	Area (1000 hectares)			Percentual (%)		
Rio Grande do Sul	7,622.07	7,541.25	1,635.51	19.1	−8.8	32.2
Pampa Biome municipalities	5,915.14	6,583.38	1,374.16	24.0	−7.3	33.4
Total analized regions	936.0	1888.0	429.9	45.2	−2.9	36.5
Western border	206.08	814.57	137.05	39.8	13.6	68.3
Alegrete	107.65	500.92	76.08	36.9	5.0	55.8
Uruguaiana	98.43	313.64	60.97	43.2	30.8	86.9
Campanha	200.53	410.87	112.83	104.2	−2.3	5.0
Bagé	60.04	185.74	57.01	133.9	5.7	19.8
Dom Pedrito	140.50	225.13	55.83	93.7	−8.1	−6.8
South	167.78	231.97	51.29	84.8	−13.8	−0.2
Santa Vitória do Palmar	100.40	144.47	36.87	59.7	−17.6	36.0
Jaguarão	67.38	87.50	14.43	141.4	−6.6	−40.6
Central	196.91	140.31	49.43	26.0	−30.0	12.9
Rio Pardo	63.17	50.19	25.69	25.7	−29.8	89.8
Cachoeira do Sul	133.74	90.13	23.73	26.1	−30.2	−21.5
Northwestern border	164.73	290.28	79.30	8.5	−13.7	156.9
São Borja	121.63	107.98	35.23	4.1	−6.5	69.8
Itacurubi	10.11	74.76	7.80	17.8	4.6	49.5
Santiago	32.99	107.55	36.27	25.1	−28.1	640.5

Source: Adapted from IBGE (2006, 2017) (Censo Agropecuário 2006; Censo Agropecuário 2017).

5

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

It was observed that rural establishments larger than 500 ha represent more than 50% (calculated to be 73.6%) of the total area of establishments (Table 1) and are characterized as livestock production and commercial agricultural regions (Andreatta, 2009).

These regions are also characterized by the presence of the largest effective cattle herds, representing almost a quarter of the cattle herd of the Rio Grande do Sul state and more than one-third of that in the BPB municipalities (IBGE, 2004b). The largest cattle herds are observed in the WB and C regions, which are the traditional beef cattle producing regions (Table 2).

Land use was marked by the presence of natural grasslands. Despite a decrease in their share in agricultural land use, natural grasslands are still a fundamental resource for farming in the BPB. In the last two decades, increasing agricultural activities in the biome caused an increase of the number of temporary crops and cultivated pastures, especially soybean (MapBiomas, 2021).

In the last decade, all regions showed an increase in temporary crop areas, mainly C and S with increases of 104.2% and 84.8%, respectively (Table 3).

2.1. Sustainability index proposal

The proposal for a sustainability index to assess the sustainability in agricultural production systems in a simple, practical, and robust manner came from the approximation of the SAFA guidelines (FAO, 2013, 2014), which were used as a source for indicators in the construction of the index. The framework is divided into four dimensions: economic resilience (ECO), social well-being (SOC), environmental integrity (ENV), and good governance (GOV).

Each dimension is split into themes, each having subthemes, and these subthemes are measured through a specific set of indicators, for which SAFA describes the metrics and measurement methods (Table 4). We chose a subset of these dimensions, themes, subthemes, and indicators was selected to build the sustainability index (iSus).

Table 4 - Selected and SAFA (FAO) dimensions, themes, subthemes, and indicators

Dimensions	Themes		Subthemes		Indicators	
	SAFA	Selected	SAFA	Selected	SAFA	Selected
Good governance	5	-	14	-	19	-
Environmental integrity	6	4	14	-	52	8
Economic resilience	4	3	14	-	26	6
Social well-being	6	3	16	-	19	6
Total	21	10	58	-	116	20

2.1.1. Indicator selection

The SAFA guidelines have 116 indicators, which make assessment and monitoring difficult. Therefore, different criteria were used for the selection of indicators.

In the ENV dimension, three types of indicators were considered: i) performance, ii) practices, and iii) objectives. Out of these, performance-measuring indicators were considered to be more consistent and were selected to make the iSus more robust. In addition, indicators measuring water conservation and management practices were also selected. The definitions and descriptions of the indicators available in the SAFA database, i.e., a) their relevance to the type of enterprise (farm level); b) the metric used (with preference for quantitative measures); and c) measurement limitations, were also utilized.

6

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

For a simplified rating of the priorities, subthemes were removed from the analyses, as they could be misunderstood and confused with indicators. Hence, three dimensions, 10 themes, and 20 indicators (Table 5) were selected and submitted to an analytic hierarchy process (AHP). Recent studies analyzed themes and indicators similar to those used in this work (Australian Beef Sustainability Framework, 2020; Van der Linden et al., 2020). Subsequently, the indicators were categorized into high, medium, and low priority levels based on the statistical outcomes of the frequency means.

Table 5 - Dimensions, themes, and indicators abbreviations selected for the Sustainable index to analyze the Brazilian Pampa biome

Dimension	Theme	Indicator	Abbreviation
Economic resilience (Eco)	Investment	Net revenue	NRe
		Production costs	PCo
	Vulnerability	Product diversification	PDf
		Net cash flow	NCF
	Product information and quality	Traceability system	TSy
		Certificated production	CeP
Environmental integrity (Env)	Water	Water management	Wma
	Land	Soil physic structure	SPS
		Soil organic matter	SOM
		Land cover and use changes	LCC
	Biodiversity	Key species abundance and diversity	KSD
		Production diversity	PDv
	Animal health	Animal health	AHe
		Appropriate animal husbandry	ANH
Social well-being (Soc)	Decent livelihood	Wage level	WLe
		Capacity development	CDe
	Labor rights	Employment relationship	ERe
		Child labor	CLb
	Human health and safety	Safety and health trainings	SHT
		Health coverage and access to medical care	HCMC

2.2. Analytic hierarchy process

After the selection of dimensions, themes, and indicators, experts were consulted to rank priority ratings according to the AHP (Saaty, 1990). The AHP is used in different areas (Kroenke and Hein, 2011; Ribeiro and Alves, 2016; Da Silva et al., 2019). Recently, Dabkiene et al. (2021) used AHP to create an index to assess agri-environmental situations in Eastern European farms based on weighted indicators. In this process, paired comparisons occur at different hierarchical levels. Experts evaluate and grant values on a scale of 1 to 9, where 1 corresponds to equivalent priority between parameters (i.e., no priority) and 9 corresponds to top priority for one of the two parameters (i.e., absolute priority) (Saaty, 1990).

For the AHP, an electronic form was developed in Google Forms. In the initial stages of development, the form was sent to a few experts for a pretest to improve and validate it. Subsequently, the form was sent to 28 experts in the selected regions for further evaluation, which made it possible to establish priority levels for selected dimensions, themes, and indicators. The experts were selected according to the following criteria: at least 10 years of experience in agricultural activities and a degree of *lato sensu* specialization.

Experts were invited from a) teaching and research institutions, b) beef production systems (producers and consultants), and c) retailers and service provider companies, to participate in the study. Among

7

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

the 28 experts invited 39% of them had *lato sensu* degree, 29% had master degree and 32% PhD degree. About the experience in the farming sector, 42.9% of experts had at least 25 years of experience, and 39.3% were working at beef production systems, while 32.1% in teaching and research institutions.

Experts evaluated the priorities that would be given to dimensions, themes, and indicators for the index setup while answering the electronic form. Results of these comparisons defined the local priorities, which are assessed at the same hierarchical level. The product of the local priority of a hierarchy and that of a lower hierarchy determines the global priority of the lower hierarchy. Using equations (1) and (2), we calculated the global priority of themes and indicators, respectively.

$$WT_i = LD_i \times LT_i \tag{1}$$

$$WI_i = LD_i \times LT_i \times LI_i \tag{2}$$

in which WT_i = global priority of i-th theme; LD_i = local priority of i-th dimension; LT_i = local priority of i-th theme; LI_i = local priority of i-th indicator; and WI_i = global priority of i-th indicator.

In his proposal, Saaty (1990) established parameters to validate the priority values given to components of each hierarchy in the rating matrix. The method of Vargas (2010) was used as a basis for the calculations, and the geometric mean method (Bajwa et al., 2008) was used to calculate the major auto-value of the matrix (λ max). From here, we obtained the consistency ratio (CR) to consolidate the rating matrix, in which consistency values up to 0.1, considered acceptable. For the calculation of CR, consistency index (CI) and random index (RI) were used. From equation (3), we obtained the CI:

$$CI = \frac{\lambda - n}{n - 1} \tag{3}$$

in which CI = consistency index; $\lambda\ max$ = major auto-value of matrix; and n = number of parameters compared.

CR was calculated from equation (4), in which CI was from equation (3), and RI was a function of the number of parameters compared (Table 6) (Saaty, 1990).

$$CR = \frac{CI}{RI} \tag{4}$$

in which CR = consistency ratio; CI = consistency index; and RI = random index.

This analysis must be conducted to control subjectivity in the priority rating so that the ratings are consistent for evaluation. Otherwise, the ratings should be adjusted by experts to maintain consistency. With an increase in the elements of comparison, there is an increase in the probabilities of inconsistent ratings.

2.3. BPB sustainability index

The sustainability index (Figure 2) was established by the sum of products of global priorities of indicators from the assessment of farming systems:

$$iSus = \sum_l w_i \times VI_i \tag{5}$$

in which *iSus* = sustainability index*; w_i* = global priority for *i*-th indicator; and VI_i = assessment value for *i*-th indicator.

Therefore, the final value of iSus will always be between 1 score (parameters established by the indicator are not identified) and 5 score (parameters established by the indicator are fully identified) as a function of evaluation performed in farms.

8

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

Table 6 - Weight of indicator and axes correlations in principal component analysis (PCA)

Indicators	Axis 1	Axis 2
Water management	0.093	0.752
Soil physic structure	−0.123	0.405
Soil organic matter	0.439	0.314
Land cover and use changes	0.147	0.430
Key species abundance and diversity	0.439	0.313
Production diversity	0.325	0.205
Animal health	0.274	0.097
Appropriate animal husbandry	0.307	0.047
Net revenue	−0.748	−0.092
Production costs	−0.359	0.052
Product diversification	−0.626	0.061
Net cash flow	−0.437	−0.085
Traceability system	−0.142	−0.411
Certificated production	0.022	−0.056
Wage level	−0.111	−0.407
Capacity development	0.633	−0.323
Employment relationship	0.060	−0.503
Child labor	0.377	−0.591
Safety and health trainings	0.557	−0.258
Health coverage and access to medical care	0.054	−0.327
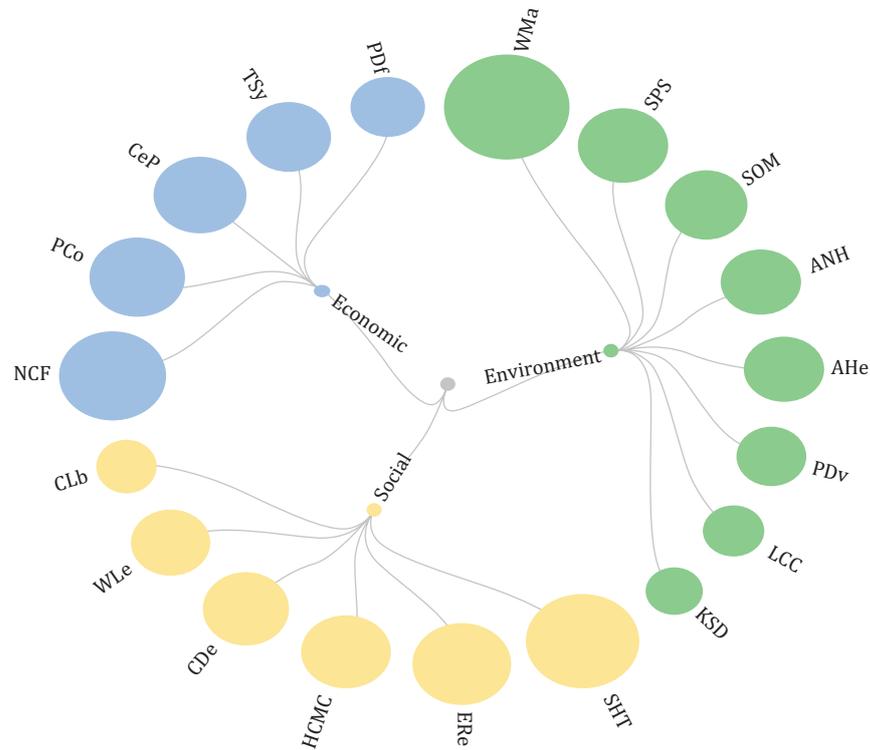
NCF - net cash flow; PCo - production costs; CeP - certificated production; TSy - traceability system; PDf - product diversification; WMa - water management; SPS - soil physic structure; SOM - soil organic matter; ANH - appropriate animal husbandry; AHe - animal health; PDv - production diversity; LCC - land cover and use changes; KSD - key species abundance and diversity; SHT- safety and health trainings; ERe - employment relationship; HCMC - health coverage and access to medical care; CDe - capacity development; WLe - wage level; CLb - child labor.

Figure 2 - Sustainability index for the Brazilian Pampa biome, dimensions, and indicators with priorities within the index.

9

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

2.4. Statistical analysis

Correlation of dimensions, themes, and indicators were performed using the Pandas Profiling function, "Pandas" package (Reback et al., 2020) in the Jupyter notebook software. Averages of the dimensions and themes were compared by performing a Kruskal–Wallis test with a Dunn post-hoc. Principal component analysis (PCA) was conducted to understand the interrelationships among indicators. PERMANOVA was also performed to verify whether the perceptions of experts were related to their regions of activity, as well as for a comparison of averages using t-test to analyze differences between average priorities of indicators. The analyses were conducted in RStudio Desktop software, considering a significance value of 95%.

3. Results

The ratings of 28 experts from different regions (six from WB, seven from NB, six from C, five from Ce, and four from S) were analyzed. The ratings did not exceed the CR value of 0.1, maintaining consistency.

3.1. Dimension and themes analysis

Dimensions presented similar priority values (Figure 3), indicating that no dimension was an absolute priority in the experts' opinion. The Kruskal-Wallis test did not show any differences (P = 0.849) between the dimensions. The themes with the highest priority were Investment (ECO), Human health and safety (SOC), and Water and Land (ENV) (Figure 3).

Among the themes, we found differences between investment and animal health (P = 0.04) and biodiversity (P = 0.04), as well as between health and human safety and animal health (P = 0.05) and biodiversity (P = 0.05).
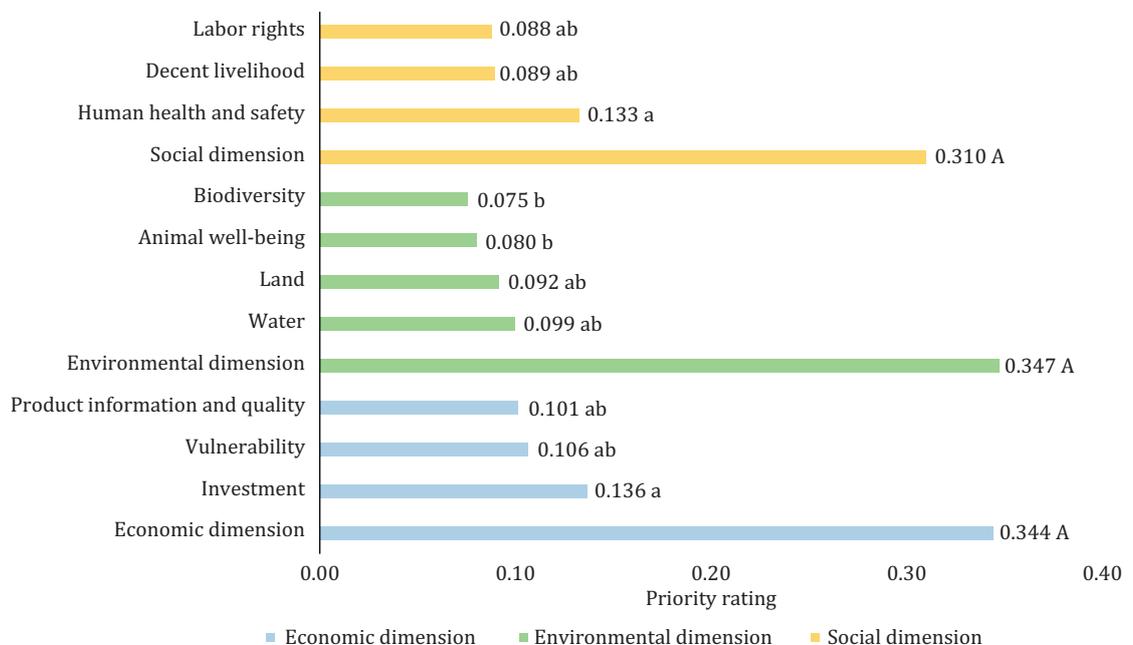

Means with distinct uppercase letters differentiate dimensions, distinct lowercase letters differentiate themes, with significance level by Kruskal-Wallis test (P<0.05).

Figure 3 - Priority level for dimensions and themes in sustainability index by experts' perceptions in the Brazilian Pampa biome by chi-square analysis.

10

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

3.2. Comparisons of indicator means and priority groups

Child labor (CLb) and land cover and use changes (LCC) indicators presented similar averages (Figure 4), and together with the key species abundance and diversity (KSD) indicator, were assigned the lowest priority. The averages of these indicators were lower than those of water management (WMa), safety and health trainings (SHT), and net revenue (NRe).

The net cash flow (NCF) indicator also differed from the KSD indicator. Additionally, WMa had a higher average than soil physics structure (SPS), whereas the rest of the indicators had lower averages. Thus, all indicators were grouped into high-, medium-, and low-priority indicators. High-priority indicators were those closer to the WMa indicator, while medium-priority indicators were close to SHT, NRe, and NCF but further from WMa, and low-priority were those that differed from these two groups.
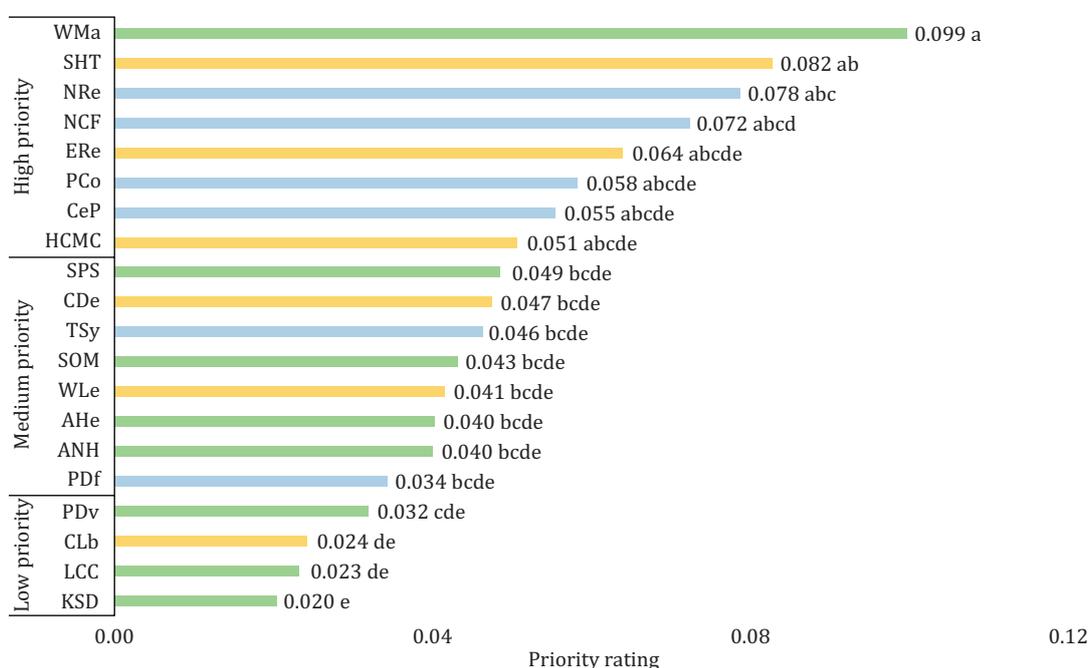
WMa - water management; SHT - safety and health trainings; NRe - net revenue; NCF - net cash flow; ERe - employment relationship; PCo - production costs; CeP - certificated production; HCMC - health coverage and access to medical care; SPS - soil physic structure; CDe - capacity development; TSy - traceability system; SOM - soil organic matter; WLe - wage level; AHe - animal health; ANH - appropriate animal husbandry; PDf - product diversification; PDv - production diversity; CLb - child labor; LCC - land cover and use changes; KSD - key species abundance and diversity.
Mean with distinct lowercase letters differ with significance level P<0.05.

Figure 4 - Comparison of means by T test, and priority groups of indicators.

3.3. Regional comparison of indicators

No differences were observed between the indicators of the regions (P = 0.11), according to the opinions of experts based on their regions and the indicators. Overlapping areas (Figure 5) indicated similar opinions among the regions of the BPB.

Capacity development (CDe), SHT, product diversification (PDf), and NRe were the main indicators that explained the variations in data in axis 1 of the PCA. This axis explained 14.9% of the data variation (Table 4).

The axis 2 (Table 4), explained 12.1% of variations in data, and WMa, LCC, ERe, and CLb were the main indicators that explained this variation.

11

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.
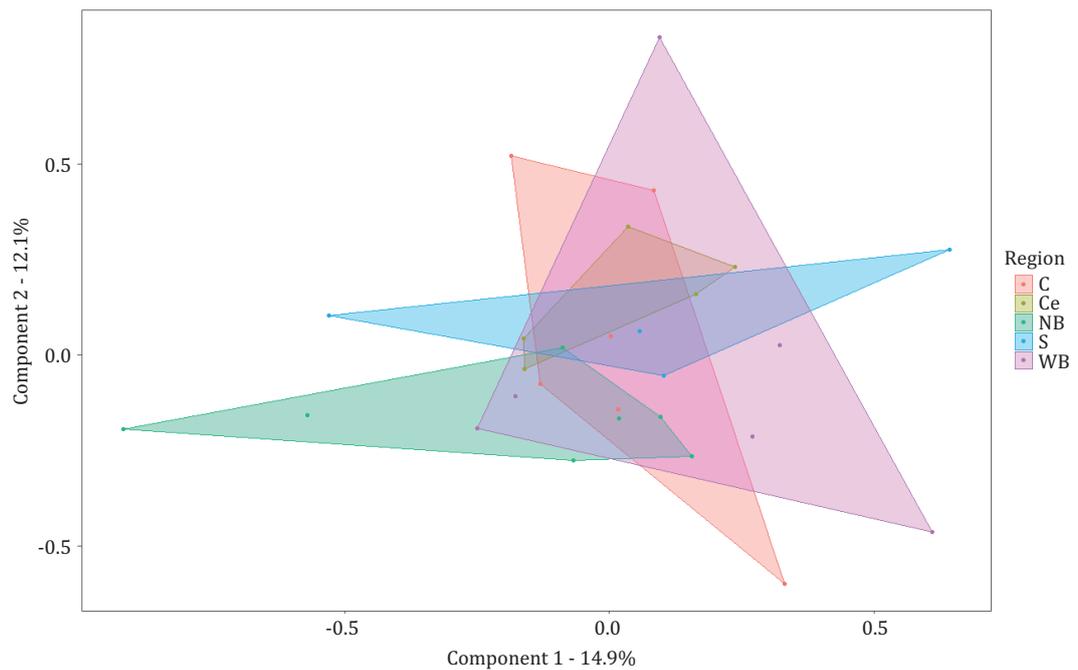
WB - Western border; NB - Northwestern border; C - Campanha; Ce - Central; S - South.

Figure 5 - Principal component analysis (PCA) of expert perceptions about sustainability indicators in different regions of the Brazilian Pampa biome.

4. Discussion

Several studies have used SAFA guidelines (Kassem et al., 2017; Pérez-Lombardini et al., 2021). This framework was independently developed by the United Nations and was advantageous due to its flexibility and credibility (Bonisoli et al., 2019). Establishing a sustainability index (collection of indicators) is based on the selection of indicators provide assumptions closest to reality. Defining the scope of analysis makes it more connected (Gasso et al., 2014) with the traits and needs of the region. In this case, the expert's perceptions obtained through AHP enabled the construction of an index with a greater sensitivity towards local reality.

Marchand et al. (2014) defined the full sustainability assessment (FSA) and rapid sustainability assessment (RSA) tools. The proposed index falls within the RSA. In such cases, it was reported that this type of tool allows analyses to be simpler and based on readily available information. In addition, RSA allows a larger number of farm systems to be evaluated, encouraging farmers to adopt sustainable principles and practices (Marchand et al., 2014). Hence, by identifying specific problems and concerns of farmers, they can be encouraged to adopt evaluations with FSA (Marchand et al., 2014). Thus, using the index allows for a more objective and simplified analysis. This objectivity acts both as a limitation in using the tool, and as a more agile and cost-effective way to carry out farming. However, this objectivity is also a limitation, as it does not encompass all the factors involved in sustainability. This is because, in this study, we sought to simplify the SAFA guidelines. The use of the proposed index allows the assessment of a broad group of farm systems, enabling a regional diagnosis, in addition to promoting the adoption of sustainable practices and principles.

4.1. Themes

The investment theme denotes the prioritization of financial management of farm systems by the experts and involves the NRe and production cost (PCo) indicators and, therefore, the profitability of

production systems. Irisarri et al. (2019) identified price fluctuation as the main factor for variation of net income in pasture cattle production systems in the USA. Dos Reis et al. (2020) demonstrated that the use of integrated crop and livestock systems increased the profitability of typical production systems in the state of Mato Grosso, Central-Western Brazil, in relation to specialized systems. Therefore, income generation is also based on the diversification of production.

In this sense, estimating the production costs in beef cattle production systems are complex to be obtained, because of its diversity, and in some cases, it's not even used in Brazilian cattle operations (Wedekin et al., 2017). In beef cattle the main components of operational costs in breeder systems are feeding, soil pH correctives and fertilizers, and reproduction, while those in feeder systems are animal purchases for replacement, soil correctives and fertilizers, and nutrition (ABIEC, 2020).

The theme vulnerability highlights product diversification and cash flows. Wedekin et al. (2017) defined the volatility of commodity prices as the intensity and frequency of price fluctuations, which is an inherent feature of commodities. Therefore, the higher the volatility of commodities, the greater the risk for economic agents involved (Wedekin et al., 2017), exposing them to vulnerabilities. Bell et al. (2021) modeled the adoption risk of different proportions of crops and livestock in Australian production systems, with varying prices of commodities, climate, and production. They identified that systems that performed two activities, even if they were not integrated, presented lower economic risks than models of specialized production systems.

In the human health and safety theme, experts prioritize the inherent risks of agricultural activities. Owing to the distances between the workplace and health care centers, it is difficult to ensure adequate health conditions, ranging from access to medical care to the ability to prevent diseases and accidents. Medeiros (2018) identified the main occupational risks and diseases experienced by workers in Brazilian agriculture. Employment relations in Brazil are governed by law (CLT, Law No. 5,452, of May 1, 1943; Brasil, 1943), which provides a basis for workers' rights and obligations of the employers, with rural activity-specific rules (Law No. 5,889, of June 8, 1973; Brasil, 1973).

The priority of the water theme can be explained by the presence of irrigated crops in the BPB and the occurrence of La Niña and El Niño phenomena (Dijkstra, 2006). La Niña has the greatest damage potential, as it is associated with below-average rainfall, causing very intense periods of drought that decrease agricultural production (Fontana et al., 2018; Pereira et al., 2018). Another important issue is the correct use of soil and the pasture management. Establishing the correct sward height and grazing intensity improves soil-related attributes (Carvalho et al., 2010). Soil and animal management is fundamental for reducing environmental impacts, obtaining better financial results, and ensuring jobs and livelihoods for people, thus promoting sustainability (Chemineau, 2016). Improving road infrastructure and access to cities, as well as the flow of production.

The biodiversity theme evaluates the changes that occurred in the BPB owing to the substitution of natural grasslands by farmlands, which may cause biodiversity losses due to continued degradation of native environments by the presence of weeds such as Anonni grass (*Eragrostis plana*) (Medeiros and Focht, 2007; Medeiros et al., 2014) and buva (*Conyza bonariensis*) (Vargas et al., 2007). On the other hand, natural grasslands can be a source of ecosystem services (Pillar et al., 2015). In 2021, the Brazilian government approved a law (Law No. 14,119, of January 13, 2021; Brasil, 2021) that defines and regulates the payment of environmental services, which can be considered as a stimulus for the conservation of these environments.

Identifying whether animal management is consistent with the recommended protocols of animal welfare (OIE, 2021) is a topic of concern for Brazilian society (Queiroz et al., 2018) and for sustainability (Chemineau, 2016). The major disease in beef cattle in the BPB is cattle tick fever, caused by *Babesia bovis, Babesia bigemina,* and *Anaplasma marginales* and transmitted by ticks (*Boophilus sp.*) (Andreotti et al., 2016). The potential annual productivity loss, due to the ticks, for Brazilian beef cattle was found to be approximately US$ 2.3 billion (Grisi et al., 2014). Embrapa (2020) established that animal welfare is an important factor for the viability of beef cattle.

13

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

4.2. Indicators

We can associate the similarities in the perceptions demonstrated in PCA by the regional characteristics such as the size of establishments (Table 1), the importance of beef cattle due to effective herds (Table 2), and participation of natural grasslands (Table 3), along with increase in the number of temporary crops of these regions (Table 3). These were the common characteristics in all the regions of the analysis. The comparison of the global priority averages showed differences between the indicators. Thus, three priority groups of indicators were separated: high, medium, and low.

4.2.1. High-priority indicators

Among the high-priority indicators, WMa practices that optimize the production systems are maintenance of irrigation systems and supply of water for crops and livestock. In the experts' perception, WMa has a high priority, as drought events are common and the irrigation of crops is an important economic activity.

The ERe, SHT, and HCMC indicators, and indicators of the social dimension, are actively involved in labor legislation in Brazil which may point to reasons for the high priority of these indicators. This legislation entails many obligations to employers to maintain their employees' well-being at farm facilities, such as the use of individual protection equipment, which is mandatory.

Most of the indicators of the economic dimension were of high priority. The NRe, NCF, and PCo indicators measure the viability of the activity, the ability to manage resources in daily life, and the efficiency of use of resources. The prioritization of these indicators by experts may be associated with low-income generation and the necessity to increase revenues in beef production systems. Therefore, increasing productivity is imperative to achieve sustainability. The implementation and improvement of management is a central theme in livestock production in Brazil (Embrapa, 2020).

4.2.2. Medium-priority indicators

In the perception of experts, most indicators of the ENV dimension were grouped under medium priority. The SPS and soil organic matter (SOM) indicators denote soil management. This assignment is owing to the wide presence of natural grasslands, despite its decrease in the face of the advancement of soybean cultivation. The animal health (AHe) and appropriate animal husbandry (ANH) indicators are related to animal health and welfare. This rating is associated with the type of animal breeding that is widely made in grasslands.

In the experts' perceptions, TSy brings few benefits to system income and increases costs with employees and traceability materials. The disinterest of farmers in traceability is one of the major challenges for livestock production (Embrapa, 2020). Alternatively, diversification of products allows farmers to escape seasonality of production and enables marketing of different products at the most favorable time for each of them. Although PDf can bring resilience to production systems, soil and climate traits limit this diversification.

The capacity development (Cde) and wage level (Wle) indicators denote the improvement of the skills and financial conditions of the people involved in the production. Wage level seems to affect productivity (Policardo et al., 2019), such as training (Konings & Vanormelingen, 2015). Embrapa (2020) lists qualification and retention of professionals among the megatrends for 2040 livestock production, which will be one of the great challenges to be overcome by the activity.

4.2.3. Low-priority indicators

According to experts, CLb is a low-priority indicator, which may be associated with the care that specialists perceive in production systems, by not using child labor in any way. There is specific legislation dealing with this issue (Law No. 8,069 on July 13, 1990; Brasil, 1990). In its 4th chapter, the

14

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

legislation describes the conditions in which children and teenagers can work. Children up to 14 years of age are prohibited from working. Thus, the experts perceive that child labor is an issue that is under control but cannot be generalized.

Additionally, production diversity (Pdv), LCC, and KSD indicators were assigned low-priority by experts with respect to other environmental indicators. Pdv points to the cultivation and rearing of alternate plant and animal species, respectively. In this way, options for crop rotation and breeding of other animal species are expanded. The reasons for considering these indicators of low-priority are the sociocultural formation of the region (BPB) and restrictions of agricultural activities, mainly by soils and climate limitations, denoting very consolidated production systems.

Expanding the adoption of management tools must be a priority among agents within the farm-gate (Figure 6), while the development of user-friendly instruments and capacity bulding for these agents are challenges for agents outside the gate (Figure 7). Economic viability is fundamental for the effective participation of agricultural production systems in improving people's well-being, as well as conserving the environment by following sustainable practices, and avoiding immediate productive responses that often degrade the environment.

Water is a limiting factor for agricultural production, but to use it with due caution, the construction of artificial reservoirs must allow for the regulation of its flow into the environment. There are laws and protocols governing the construction of dams and hydraulic barriers (Resolution 512/2024, Consema). Speeding up these processes, without losing technical and legal criteria, would help to expand measures for water reserves. Adopting efficient irrigation systems is an important measure to increase the sustainability of agricultural production systems, which helps in maintaining crop productivity with less water. Compared to flood irrigation systems, sprinkler irrigation systems can reduce water use by up to 50% (Giacomelli, 2019). Developing new technologies for efficient water use and loss reduction can further aid in sustainability. Combining correct soil management with this allows water to maintain its recharge flow from watercourses and underground reservoirs, reducing losses and increasing the resilience of the systems.
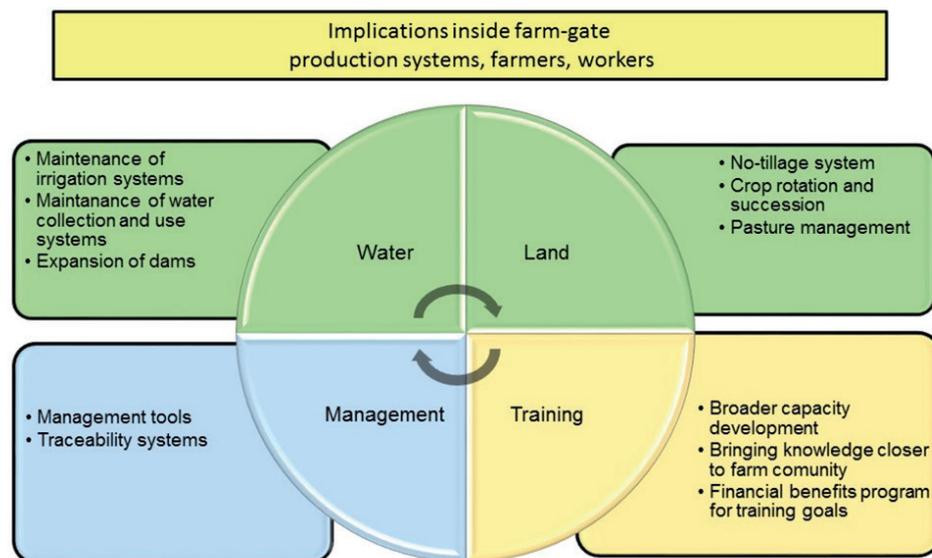

Figure 6 - Implications inside gates that can contribute to improve sustainability in agricultural production in Brazilian Pampa biome.

15

Sustainability index approach of the Brazilian Pampa biome
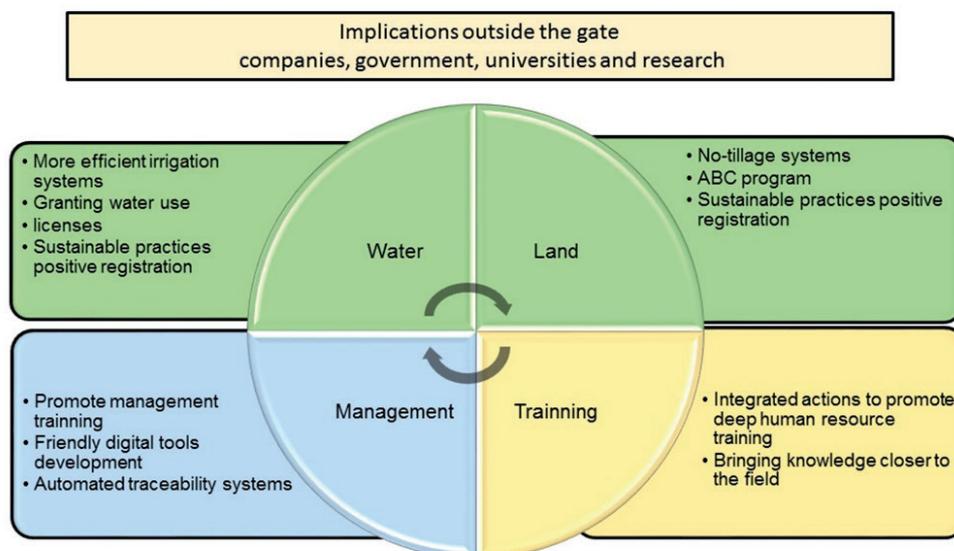Queiroz Filho et al.

Figure 7 - Implications outside gates that can contribute to improve sustainability in agricultural production in Brazilian Pampa biome.

Promoting the training of people involved in agricultural production must be a priority for all segments of the sector, as it can make all supply chain links more efficient. Creating labor qualification programs that promote significant change must not be limited to technological issues. They should also involve people to improve their knowledge and abilities to ensure better living conditions and social advancement, offering better prospects for new generations.

Identifying production systems with good production practices and replicating these examples, either by certification or recognition through awards, may not be enough to expand sustainable practices and processes. Creating positive registrations and granting of tax benefits for sustainable production systems can bring effective results.

Ultimately, the proposed index demonstrates potential to address the specific demands of livestock production systems by improving the practicality and applicability of sustainability assessments in a simplified yet robust manner. Simplification of the index also acts as a limitation to this method. However, this simplification was chosen because of other advantages, such as the agility of analyses and low cost.

The experts' perceptions contributed to building an index with regional priorities, which allowed sustainability assessments to reflect the analyzed reality. Investment (ECO), safety and health training (SOC), and water and land (ENV), were the high-priority themes in the perception of experts. Thus, the profitability of production systems, mainly in relation to income generation, worker training to prevent accidents and diseases through prevention protocols, soil management aimed at conserving physical structure by adopting practices that avoid compaction and erosion, and efficient water management through the maintenance of irrigation systems and water collection, are points that emerged from the perceptions of specialists.

5. Conclusions

The methodology used was able to produce a sustainability index (iSus) for the BPB within a variety of proposed themes. Additionally, tools for rapid analysis promote farmers' incentives to adopt sustainable practices, with deeper and more complete sustainability analysis for their farm systems. The use of this index will allow sustainability to be measured in the BPB, and the studied factors will be very important in these assessments.

16

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

Establishing public policies and practices that promote the sustainability of agricultural production, either by expanding programs to finance sustainable practices, or by creating tax benefit projects for farmers who apply sustainable practices, should be premised on the assessment of these production systems, and this study contributes to this sense, by proposing a sustainability index objective and applicable to the BPB.

We believe that this study can inspire future analyses that consider other biomes and production systems, with specific indicators and practices for different situations, with new balancing and hierarchical analyses of processes, in order to adapt sustainability assessment indexes, making this type of assessment actually feasible.

Data availability

The entire dataset supporting the results of this study is available upon request to the corresponding author.

Author contributions

Conceptualization: Queiroz Filho, L. A. V. and Barcellos, J. O. J. **Data curation:** Queiroz Filho, L. A. V.; Oliveira, T. E. and Köbrich, C. **Formal analysis:** Queiroz Filho, L. A. V. and Oliveira, T. E. **Funding acquisition:** Barcellos, J. O. J. **Investigation:** Queiroz Filho, L. A. V. **Methodology:** Queiroz Filho, L. A. V. **Project administration:** Queiroz Filho, L. A. V. **Supervision:** Barcellos, J. O. J. **Validation:** Barcellos, J. O. J. **Visualization:** Zago, D. **Writing – original draft:** Queiroz Filho, L. A. V.; Oliveira, T. E. and Zago, D. **Writing – review & editing:** Köbrich, C.; Bayer, C. and Barcellos, J. O. J.

Conflict of interest

The authors declare no conflict of interest.

Financial support

References

ABIEC - Associação Brasileira das Indústrias Exportadoras de Carne. 2020. Beef Report 2020 - Perfil da pecuária no Brasil. Available at: <http://abiec.com.br/publicacoes/beef-report-2020>. Accessed on: Sept. 28, 2025.

ABIEC - Associação Brasileira das Indústrias Exportadoras de Carne. Beef Report 2023 - Perfil da pecuária do Brasil. Available at: <https://abiec.com.br/publicacoes/beef-report-2023>. Accessed on: July 10, 2025.

Adegbeye, M. J.; Reddy, P. R. K.; Obaisi, A. I.; Elghandour, M. M. M. Y.; Oyebamiji, K. J.; Salem, A. Z. M.; Morakinyo-Fasipe, O. T.; Cipriano-Salazar, M. and Camacho-Díaz, L. M. 2020. Sustainable agriculture options for production, greenhouse gasses and pollution alleviation, and nutrient recycling in emerging and transitional nations - An overview. Journal of Cleaner Production 242:118319. https://doi.org/10.1016/j.jclepro.2019.118319

Andreatta, T. 2009. Bovinocultura de corte no Rio Grande do Sul: um estudo a partir do perfil dos pecuaristas e organização dos estabelecimentos agrícolas. 2009. Tese (D.Sc.). Universidade Federal do Rio Grande do Sul, Porto Alegre.

Andreotti, R.; Garcia, M. V.; Reis, F. A.; Rodrigues, V. S. and Barros, J. C. 2016. Proposta de controle de carrapatos para o Brasil Central em sistemas de produção de bovinos associados ao manejo nutricional no campo. Documentos, 214. Embrapa Gado de Corte, Campo Grande.

Australian Beef Sustainability Framework. 2020. Australian Beef Sustainability Framework Annual Report. Available at: <https://www.sustainableaustralianbeef.com.au/>. Accessed on: Oct. 07, 2020.

Barcellos, J. O. J.; Suñe, Y. B. P.; Semmelmann, C. E. N.; Grecellé, R. A.; Da Costa, E. C.; Montanholi, Y. R. and Christofari, L. 2004. A bovinocultura de corte frente a agriculturização no sul do Brasil. p.13-30. In: 11º Ciclo de Atualização em Medicina Veterinária. UDESC, Lages.

Bajwa, G.; Choo, E. U. and Wedley, W. C. 2008. Effectiveness analysis of deriving priority vectors from reciprocal pairwise comparison matrices. Asia-Pacific Journal of Operational Research 25:279-299. https://doi.org/10.1142/S0217595908001754

Bell, L. W.; Moore, A. D. and Thomas, D. T. 2021. Diversified crop-livestock farms are risk-efficient in the face of price and production variability. Agricultural Systems 189:103050. https://doi.org/10.1016/j.agsy.2021.103050

Boldrini, I. I.; Overbeck, G. E. and Trevisan, R. 2015. Biodiversidade de plantas. p.51-60. In: Pillar, V. P. E. and Lange, O. (eds.). Os campos do Sul. Rede Campos Sulinos - UFRGS, Porto Alegre.

Bonisoli, L.; Galdeano-Gómez, E.; Piedra-Muñoz, L. and Pérez-Mesa, J. C. 2019. Benchmarking agri-food sustainability certifications: Evidences from applying SAFA in the Ecuadorian banana agri-system. Journal of Cleaner Production 236:117579. https://doi.org/10.1016/j.jclepro.2019.07.054

Brasil. 1943. Decreto-Lei nº 5.452, de 1º de maio de 1943. Aprova a Consolidação das Leis do Trabalho. Available at: <https://www2.camara.leg.br/legin/fed/declei/1940-1949/decreto-lei-5452-1-maio-1943-415500-publicacaooriginal-1-pe.html>. Accessed on: Nov. 15, 2020.

Brasil. 1973. Lei nº 5.889, de 8 de junho de 1973. Estatui normas reguladoras do trabalho rural e dá outras providências. Available at: <https://www2.camara.leg.br/legin/fed/lei/1970-1979/lei-5889-8-junho-1973-357971-publicacaooriginal-1-pl.html>. Accessed on: Nov. 15, 2020.

Brasil. 1990. Lei nº 8.069, de 13 de julho de 1990. Dispõe sobre o Estatuto da Criança e do Adolescente, e dá outras providências. Available at: <https://www2.camara.leg.br/legin/fed/lei/1990/lei-8069-13-julho-1990-372211-publicacaooriginal-1-pl.html>. Accessed on: Nov. 15, 2020.

Brasil. 2021. Lei nº 14.119, de 13 de janeiro de 2021. Institui a Política Nacional de Pagamento por Serviços Ambientais; e altera as Leis n. 8.212, de 24 de julho de 1991, 8.629, de 25 de fevereiro de 1993, e 6.015, de 31 de dezembro de 1973, para adequá-las à nova política. <https://www.planalto.gov.br/ccivil_03/_ato2019-2022/2021/lei/l14119.htm>. Accessed on: Feb. 25, 2021.

Brum Neto, H. and Bezzi, M. L. 2008. Regiões culturais: a construção de identidades culturais no Rio Grande do Sul e sua manifestação na paisagem gaúcha. Sociedade & Natureza 20:135-155. https://doi.org/10.1590/S1982-45132008000200009

Calicioglu, O.; Flammini, A.; Bracco, S.; Bellù, L. and Sims, R. 2019. The future challenges of food and agriculture: an integrated analysis of trends and solutions. Sustainability 11:222. https://doi.org/10.3390/su11010222

Carvalho, P. C. F.; Wallau, M. O.; Bremm, C.; Bonnet, O.; Trindade, J. K.; Rosa, F. Q.; Freitas, T. S.; Moojen, F. G. and Nabinger, C. 2019. Nativão: + de 30 anos de pesquisa em campo nativo. Via Pampa, Porto Alegre. Available at: <https://www.ufrgs.br/gpep/wp-content/uploads/2020/09/Boletim-Nativa%CC%83o-de-30-anos-de-pesquisa.pdf>. Accessed on: Jan. 12, 2021.

Carvalho, P. C. F.; Peterson, C. A.; Nunes, P. A. A.; Martins, A. P.; Souza Filho, W.; Bertolazi, V. T.; Kunrath, T. R.; Moraes, A. and Anghinoni, I. 2018. Animal production and soil characteristics from integrated crop-livestock systems: toward sustainable intensification. Journal of Animal Science 96:3513-3525. https://doi.org/10.1093/jas/sky085

Carvalho, P. C. F.; Anghinoni, I.; Moraes, A.; Souza, E. D.; Sulc, R. M.; Lang, C. R.; Flores, J. P. C.; Lopes, L. M. T.; Silva, J. L. S.; Conte, O.; Wesp, C. L.; Levien, R.; Fontaneli, R. S. and Bayer, C. 2010. Managing grazing animals to achieve nutrient cycling and soil improvement in no-till integrated systems. Nutrient Cycling in Agroecosystems 88:259-273. https://doi.org/10.1007/s10705-010-9360-x

Chemineau, P. 2016. Invited review: Importance of animal health and welfare for the stability of the three pillars of sustainability of livestock systems. Advances in Animal Biosciences 7:208-214. https://doi.org/10.1017/S2040470016000145

Dabkiene, V.; Balezentis, T. and Streimikiene, D. 2021. Development of agri-environmental footprint indicator using the FADN data: Tracking development of sustainable agricultural development in Eastern Europe. Sustainable Production and Consumption 27:2121-2133. https://doi.org/10.1016/j.spc.2021.05.017

Da Silva, L. A.; Hernández, C. T. and Brandalise, C. 2019. Avaliação de criticidade de peças sobressalentes utilizando o método analytic hierarchy process com ratings. Sistemas & Gestão 14:166-176.

Dijkstra, H. A. 2006. The ENSO phenomenon: theory and mechanisms. Advances in Geosciences 6:3-15. https://doi.org/10.5194/adgeo-6-3-2006

Dos Reis, J. C.; Kamoi, M. Y. T.; Latorraca, D.; Chen, R. F. F.; Michetti, M.; Wruck, F. J.; Garrett, R. D.; Valentim, J. F.; Rodrigues, R. A. R. and Rodrigues-Filho, S. 2020. Assessing the economic viability of integrated crop–livestock systems in Mato Grosso, Brazil. Renewable Agriculture and Food Systems 35:631-642. https://doi.org/10.1017/S1742170519000280

Embrapa. 2020. O futuro da cadeia produtiva da carne bovina brasileira: uma visão para 2040. Embrapa Gado de Corte, Campo Grande.

FAO - Food and Agriculture Organization of the United Nations. 2013. Sustainability Assessment of Food and Agriculture Systems - SAFA Indicators. FAO, Rome. Available at: <http://www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/SAFA_Indicators_final_19122013.pdf>. Accessed on: Jan. 12, 2020.

18

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

FAO - Food and Agriculture Organization of the United Nations. 2014. Sustainability Assessment of Food and Agriculture Systems - SAFA Guidelines. Version 3.0. FAO, Rome. Available at: <http://www.fao.org/3/i3957e/i3957e.pdf>. Accessed on: Jan. 12, 2020.

Fontana, D. C.; Junges, A. H.; Bremm, C.; Schaparini, L. P.; Mengue, V. P.; Wagner, A. P. L. and Carvalho, P. 2018. NDVI and meteorological data as indicators of the Pampa biome natural grasslands growth. Bragantia 77:404-414.

Freitas, D. S.; Oliveira, T. E. and Oliveira, J. M. 2019. Sustainability in the Brazilian pampa biome: A composite index to integrate beef production, social equity, and ecosystem conservation. Ecological Indicators 98:317-326. https://doi.org/10.1016/j.ecolind.2018.10.012

Gasso, V.; Oudshoorn, F. W.; Olde, E. and Sorensen, C. A. G. 2014. Generic sustainability assessment themes and the role of context: The case of Danish maize for German biogas. Ecological Indicators 49:143-153. https://doi.org/10.1016/j.ecolind.2014.10.008

Garnett, T.; Appleby, M. C.; Balmford, A.; Bateman, I. J.; Benton, T. G.; Bloomer, P.; Burlingame, B.; Dawkins, M.; Dolan, L.; Fraser, D.; Herrero, M.; Hoffmann, I.; Smith, P.; Thornton, P. K.; Toulmin, C.; Vermeulen, S. J. and Godfray, H. C. J. 2013. Sustainable intensification in agriculture: premises and policies. Science 341:33-34. https://doi.org/10.1126/science.1234485

Giacomelli, R. 2019. Manejo da água e solo em arroz e soja em terras baixas. Tese (D.Sc.). Universidade Federal de Santa Maria, Santa Maria.

Gibon, A.; Sibbald, A. R. and Thomas, C. 1999. Improved sustainability in livestock systems, a challenge for animal production Science. Livestock Production Science 61:107-110. https://doi.org/10.1016/S0301-6226(99)00060-3

Godfray, H. C. J. 2015. The debate over sustainable intensification. Food Security 2:199-208. https://doi.org/10.1007/s12571-015-0424-2

Grisi, L.; Leite, R. C.; Martins, J. R. S. M.; De Barros, A. T. M.; Andreotti, R.; Cançado, P. H. D.; De León, A. A. P.; Pereira, J. B. and Villela, H. S. 2014. Reassessment of the potential economic impact of cattle parasites in Brazil. Revista Brasileira de Parasitologia Veterinária 23:150-156. https://doi.org/10.1590/S1984-29612014042

Heitschmidt, R. K.; Short, R. E. and Grings, E. E. 1996. Ecosystems, sustainability, and animal agriculture. Journal of Animal Science 74:1395-1405. https://doi.org/10.2527/1996.7461395x

IBGE - Instituto Brasileiro de Geografia e Estatística. 2006. Censo Agropecuário 2006. IBGE, Rio de Janeiro. Available at: <https://ftp.ibge.gov.br/Censo_Agropecuario/Censo_Agropecuario_2006/Segunda_Apuracao/censoagro2006_2aapuracao.pdf>. Accessed on: Nov. 15, 2020.

IBGE - Instituto Brasileiro de Geografia e Estatística. 2017. Censo Agropecuário 2017. IBGE, Rio de Janeiro. Available at: <https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/21814-2017-censo-agropecuario.html>. Accessed on: Nov. 15, 2020.

IBGE - Instituto Brasileiro de Geografia e Estatística. 2004a. Mapas de biomas e vegetação. IBGE, Rio de Janeiro. Available at: <https://www.ibge.gov.br/geociencias/informacoes-ambientais/vegetacao/10872-vegetacao.html>. Accessed on: Nov. 15, 2020.

IBGE - Instituto Brasileiro de Geografia e Estatística. 2004b. Lista de municípios dos biomas. Available at: <https://www.ibge.gov.br/geociencias/informacoes-ambientais/estudos-ambientais/15842-biomas.html>. Accessed on: Nov. 15, 2020.

Irisarri, J.; Derner, J. D.; Ritten, J. P. and Peck, D. E. 2019. Beef production and net revenue variability from grazing systems on semiarid grasslands of North America. Livestock Science 220:93-99. https://doi.org/10.1016/j.livsci.2018.12.009

Kassem, E.; Trenz, O.; Hřebiček, J. and Faldik, O. 2017. Sustainability assessment and reporting in agriculture sector. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 65:1359-1369. https://doi.org/10.11118/actaun201765041359

Konings, J. and Vanormelingen, S. 2015. The impact of training on productivity and wages: firm-level evidence. Review of Economics and Statistics 97:485-497.

Kroenke, A. and Hein, N. 2011. Avaliação de empresas por meio de indicadores de atividade: uma aplicação do método AHP. REGE - Revista de Gestão 18:605-620.

Lampert, V. N.; Canozzi, M. E. A.; McManus, C. M.; Dill, M. D.; Oliveira, T. E.; Mercio, T. Z.; Teixeira, O. S. and Barcellos, J. O. J. 2020. Modelling beef cattle production systems from the Pampas in Brazil to assess intensification options. Scientia Agricola 77:e20180263. https://doi.org/10.1590/1678-992X-2018-0263

MapBiomas, 2021. Brazilian land cover and use maps. Available at: <https://mapbiomas.org/>. Accessed on: Jan. 07, 2021.

MapBiomas. 2025. Infográficos (Pampa). Available at: <https://mapbiomas.org/>. Accessed on: July 14, 2025.

Marchand, F.; Debruyne, L.; Triste, L.; Gerrard, C.; Padel, S. and Lauwers, L. 2014. Key characteristics for tool choice in indicator-based sustainability assessment at farm level. Ecology and Society 19:46. https://doi.org/10.5751/ES-06876-190346

Marques, P. R.; Barcellos, J. O. J.; McManus, C.; Oaigen, R. P.; Collares, F. C.; Canozzi, M. E. A. and Lampert, V. N. 2011. Competitiveness of beef farming in Rio Grande do Sul State, Brazil. Agricultural Systems 104:689-693. https://doi.org/10.1016/j.agsy.2011.08.002

19

Sustainability index approach of the Brazilian Pampa biome
Queiroz Filho et al.

Medeiros, R. B. and Focht, T. 2007. Invasão, prevenção, controle e utilização do capim-annoni-2 (*Eragrostis Plana* Nees) no Rio Grande do Sul. Pesquisa Agropecuária Gaúcha 13:105-114.

Medeiros, R. B.; Focht, T.; Menegon, L. L. and Freitas, M. R. 2014. Seed longevity of *Eragrostis Plana* nees buried in natural grassland soil. Revista Brasileira de Zootecnia 43:561-567. https://doi.org/10.1590/S1516-35982014001100001

Medeiros, F. E. 2018. Riscos ocupacionais na agricultura brasileira. Dissertação (M.Sc.). Universidade Federal de Campina Grande, Pombal.

Oltjen, J. W. and Beckett, J. L. 1996. Role of ruminant livestock in sustainable agricultural systems. Journal of Animal Science 74:1406-1409. https://doi.org/10.2527/1996.7461406x

OIE. 2021. World Organization for Animal Health. Available at: <https://www.oie.int/>. Accessed on: Dec. 02, 2020.

Pereira, P. R. R. X.; Hasenack, H.; Pereira, G. R.; Dewes, H.; Canellas, L. C.; Oliveira, T. E. and Barcellos, J. O. J. 2018. Climate change and beef supply chain in Southern Brazil. Journal of Agricultural Science 156:731-738. https://doi.org/10.1017/S0021859618000667

Pérez-Lombardini, F.; Mancera, K. F.; Suzán, G.; Campo, J.; Solorio, J. and Galindo, F. 2021. Assessing sustainability in cattle silvopastoral systems in the Mexican tropics using the SAFA framework. Animals 11:109. https://doi.org/10.3390/ani11010109

Pillar, V. P.; Andrade, B. O. and Dadalt, L. 2015. Serviços ecossistêmicos. p.117-119. In: Pillar, V. P. and Lange, O. (eds.). Os campos do Sul. Rede Campos Sulinos - UFRGS, Porto Alegre.

Policardo, L.; Punzo, L. F. and Carrera, E. J. S. 2019. On the wage–productivity causal relationship. Empirical Economics 57:329-343.

Queiroz, R. G.; Domingues, C. H. F.; Canozzi, M. E. A.; Garcia, R. G.; Ruviaro, C. F.; Barcellos, J. O. J. and Borges, J. A. R. 2018. How do Brazilian citizens perceive animal welfare conditions in poultry, beef, and dairy supply chains? PLoS ONE 13:e0202062. https://doi.org/10.1371/journal.pone.0202062

Reis, J. C. L. and Saibro, J. C. 2004. Integração do arroz com pastagens cultivadas e pecuária. p.831-859. In: Gomes, A. S. and Magalhães Júnior, A. M. (eds.). Arroz irrigado no Sul do Brasil. Embrapa Clima Temperado, Pelotas; Embrapa Informação Tecnológica, Brasília.

Ribeiro, M. C. C. R. and Alves, A. S. 2016. Aplicação do método Analytic Hierarchy Process (AHP) com a mensuração absoluta num problema de seleção qualitativa. Sistemas & Gestão 11:270-281.

Reback, J.; McKinney, W.; jbrockmendel; Van den Bossche, J.; Augspurger, T.; Cloud, P.; gfyoung; Sinhrks; Klein, A.; Roeschke, M.; Hawkins, S.; Tratner, J.; She, C.; Ayd, W.; Petersen, T.; Garcia, M.; Schendel, J.; Hayden, A.; MomIsBestFriend; Jancauskas, V.; Battiston, P.; Seabold, S.; chris-b1; h-vetinari; Hoyer, S.; Overmeire, W.; alimcmaster1; Dong, K.; Whelan, C. and Mehyar, M. 2020. pandas-dev/pandas: Pandas 1.0.3 (v1.0.3). Zenodo. https://doi.org/10.5281/zenodo.3715232

Ruviaro, C. F.; Léis, C. M.; Lampert, V. N.; Barcellos, J. O. J. and Dewes, H. 2015. Carbon footprint in different beef production systems on a southern Brazilian farm: a case study. Journal of Cleaner Production 96:435-443. https://doi.org/10.1016/j.jclepro.2014.01.037

Ruviaro, C. F.; Costa, J. S.; Florindo, T. J.; Rodrigues, W.; Medeiros, G. I. B. and Vasconcelos, O. S. 2016. Economic and environmental feasibility of beef production in different feed management systems in the Pampa biome, southern Brazil. Ecological Indicators 60:930-939. https://doi.org/10.1016/j.ecolind.2015.08.042

Saaty, T. L. 1990. How to make a decision: The analytic hierarchy process. European Journal of Operational Research 48:9-26. https://doi.org/10.1016/0377-2217(90)90057-I

Streck, E. V.; Kämpf, N.; Dalmolin, R. S. D.; Klamt, E.; Nascimento, P. D.; Schneider, P.; Giasson, E. and Pinto, L. F. S. 2008. Solos do Rio Grande do Sul. UFRGS, Porto Alegre.

Van der Linden, A.; De Olde, E. M.; Mostert, P. F. and De Boer, I. J. M. 2020. A review of European models to assess the sustainability performance of livestock production systems. Agricultural Systems 182:102842. https://doi.org/10.1016/j.agsy.2020.102842

Vasconcelos, K.; Farinha, M.; Bernardo, L.; Lampert, V. N.; Gianezini, M.; Costa, J. S.; Soares Filho, A.; Genro, T. C. M. and Ruviaro, C. F. 2018. Livestock-derived greenhouse gas emissions in a diversified grazing system in the endangered Pampa biome, Southern Brazil. Land Use Policy 75:442-448. https://doi.org/10.1016/j.landusepol.2018.03.056

Vargas, R. V. 2010. Using the analytic hierarchy process (AHP) to select and prioritize projects in a portfolio. In: PMI Global Congress 32:1-22.

Vargas, L.; Bianchi, M. A.; Rizzardi, M. A.; Agostinetto, D. and Dal Magro, T. 2007. Buva (*Conyza bonariensis*) resistente ao glyphosate na região Sul do Brasil. Planta Daninha 25:573-578. https://doi.org/10.1590/S0100-83582007000300017

Wedekin, I.; Pinazza, L. A.; Lemos, F. K. and Vivo, V. M. 2017. Economia da pecuária de corte: Fundamentos e o ciclo de preços. Wedekin Consultores, São Paulo. 180p.