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Review

Emergent Research Themes on Sustainability in the Beef Cattle Industry in Brazil: An Integrative Literature Review

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Abstract: Brazil is one of the world's biggest beef producers and its largest exporter. However, beef cattle ranching is a leading cause of deforestation and habitat conversion in the Brazilian Amazon, which challenges sustainable development. We adopted the triple bottom line (TBL) as a guiding theory of sustainability and assumed the necessity of a production system-specific approach. Based on an integrative literature analysis, we aimed to assess sustainability pillars in beef cattle production. The Web of Science, Scopus and Science Direct databases were searched for studies on mitigating the adverse impacts of beef cattle production before the COVID-19 pandemic outbreak. We found 108 references in these databases, 46 of which met the criteria for eligibility assessment, and ten studies were selected for textual cluster analysis and thematic synthesis. The review shows emergent research themes on sustainability in beef cattle production. It also elaborates a conceptual model of the sustainability pillars in the technique, science, and social aspects of the beef cattle sector that may guide the managerial and political strategies for the beef cattle supply chain in Brazil and other emerging markets. This study indicates that sustainable beef cattle development requires new digital technologies and ideas about sustainable supply chain management, which provides human, environmental, and animal welfare.

Keywords: emerging markets and developing economies; sustainability; agri-food sectors; beef cattle industry; Brazil; thematic synthesis; integrative review

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1. Introduction

Brazil is classified among the emerging market and developing economies [1]. At the same time, Brazil is among the four biggest beef cattle producers in the world. It is projected that Brazil, China, the European Union and the United States will produce approximately 60% of the world's meat by 2029. Brazil is one of three countries in the Americas where beef cattle production capacity is projected to increase up till 2029; the other countries being Argentina and the United States [2]. It is expected that 81% more beef will be produced in this period in developing countries compared to 2020. This growth creates positive externalities for developing countries, such as jobs and income generation. However, some of its possible adverse effects include deforestation of green areas and habitat conversion, which consequently change the ecology and result in environmental imbalance, potential disease, pest outbreaks and the inadequate use of water and soil [3,4]. Therefore, beef cattle producers should consider systems geared towards sustainable objectives and digital technologies, as not accepting this can lead to declines in economic returns and potential social pressures. In addition, global and political tensions trigger a tendency towards sustainability. They result in more local acceptance of sustainable priorities [5,6].

Nowadays, sustainability faces tremendous challenges, and actors of all dimensions must be aware of their responsibilities by implementing relevant policies, goals and supply chain strategies. As a more profound concern, the above-mentioned aspects comprise goals that are achieved through economic and social understanding and political and industrial actors' application of sustainability improvements [7]. They can give meaning to sustainability and the search for sustainable development from two perspectives: by grouping critical limits for exploiting resources and through the interaction between resources and human society [8]. In addition, empirical evidence on sustainability has become a recurrent research subject. Experiments conducted within sustainability science use sustainability issues as their central theme and aim to clarify its causes with evidence [9].

Developed globally by politicians, the idea of the triple bottom line (TBL) highlights that the practice of sustainability comprises economic (profit), environmental (planet), and social (people) aspects. It is also commonly used by researchers. This concept of development was coined as a basis for understanding that emerging problems pointed out by sustainable development should also be analyzed from a social and ethical perspective, not only on the basis of economic and environmental issues [10]. From that moment on, activities that could be considered sustainability practices began to be studied from these three aspects: economic, environmental and social. The knowledge generated through the TBL approach has general synthetic, analytical, descriptive, explanatory, prescriptive, instructional and procedural connotations. It impacts the environment, improving environmental and social performance [11]. Sustainability concerns all economic systems and their components that may adversely affect nature and society.

The broad concept of sustainable development, anchored on the conservation of nature, is an element that comprises environmental protection [12]. From this understanding, protecting life on the planet primarily serves to maintain human and natural well-being. As a result, economic entities often consider that setting targets aligned with environmental concerns is within the scope of their operation [13]. Principally, the sustainability criteria comprise incomparable and incommensurable economic, ecological and social qualities. A standard unit of measurement of sustainability has not been developed yet. Recent studies have considered primarily financial measures of the sustainability of social security systems, environmental protection, and economic development. The overall sustainability of the economy and economic entities comprises all three dimensions. Therefore, farms, like non-farming enterprises, must implement the rules of sustainable development [14].

Urbanization and world population growth are both forcing an intensification of the use of natural resources, including land, and an increase in food production, including meat production. These trends are occurring particularly strongly in emerging markets and developing economies. Food production can be undertaken through systems with more intensive techniques or less technological intensity (i.e., extensive systems). Production systems can be classified based on resource use, mainly of farmland. They are classified as extensive, semi-intensive and intensive. The main characteristic of extensive systems is more use of natural resources compared to the intensive system. However, both ways of developing food products carry environmental and social risks. This could be evidenced by extensive breeding in Brazil, which degrades pastures and expands into the Amazon forest. At the same time, intensive breeding extends energy, pesticide and hormone use, which results in water and air contamination [15,16].

Therefore, achieving sustainable development goals requires detailed research and an understanding of how different production systems operate and their impact on the environment and society. In Brazil, the extensive production system represents approximately 80% of livestock production, focused on cow-calf operations, backgrounding and feedlots. This system is influenced by soil, climate, animal genotype and management, grasslands, and their care [16,17]. In this system, the grassland can be native or cultivated, and each grassland type requires specific care to maximize production. Cultivated grassland differs from native grassland because of technological advancements that can assist in farming/livestock integration. However, this concerns producers if their farms are the focus of environmental research and if they implement new practices. Otherwise, low investment in land and pasture, typical for extensive ranching, leads to the loss of nutrients and degradation.

The intensive system shows lower greenhouse gas emissions but more significant use of energy compared with the extensive system. An extensive system is a grassland-only regime, whereas a semi-intensive system uses grassland and supplementation. The intensive system uses grassland, supplementation and confinement. A semi-intensive production system uses technology and food supplements such as protein salts and concentrates. Agroindustry by-products such as rice bran, wheat bran and tomato pulp may be used as inputs [18,19].

Meanwhile, the intensive system uses cow-calf, backgrounding and feedlot operations and includes confining animals. The type of confinement determines the general production characteristics [17]. Brazil also has regional singularities that facilitate production diversity [18]. Generally, beef cattle production systems are divided into different stages, each with specific characteristics. They are cow-calf, backgrounding and feedlot operations (Table 1). Each of them can be studied to analyze its impact on the environment and to achieve sustainable production. These stages can be developed in several ways, individually or collectively, and may be complementary [17,20].

Table 1. Main characteristics of beef cattle production systems in Brazil.

System	Characteristics
Cow-calf	Females are bred. Males are sold after weaning (7–9 months of age). Commercialization: weaned heifers and young heifers (1–2 years) for breeding; heifers from 2 to 3 years old, cows and bulls for the slaughterhouse.
Cow-calf and backgrounding	This system is similar to the cow-calf operation. It differs from the cow-calf operation because males are retained for up to 15–18 months (young bulls) and then sold.
Cow-calf, backgrounding, and feedlot	This system is a full-cycle activity. It is similar to the previous systems. Its difference from other systems is that males are sold as finished cattle between 15 and 42 months.
Backgrounding and feedlot	This system encompasses the period of activity between calf weaning and the period in which the finished cattle are sold.
Feedlot	This system is an isolated activity. Lean cattle are fattened from 24 to 36 months.

Source: authors' elaboration based on [8,17,19,20].

As beef consumption constantly increases worldwide and the dynamics associated with beef cattle production also increase, interventions and solutions to the problems caused by a lack of sustainability practices are needed [21,22]. Studies have provided evidence of complex and systemic causes as issues continue to emerge and persist within society, like climate change, urbanization, pandemics and the loss of biodiversity [9]. In this context, TBL gains importance as a valuable tool in the initial assessment of the problem and the diagnosis of sustainability conditions. However, a production system-specific approach is necessary when considering sustainability in growing agri-food sectors. The popularity of the TBL approach has increased in emerging markets and developing economies as many researchers have sought ways to maintain continuous growth. Such initiatives have previously been shown to decrease carbon footprints in beef cattle production [3,22]; increase regional sustainability [17]; increase beef traceability, productivity and profitability [23–26]; decrease commercial emissions; and introduce new technologies for energy consumption, the usage of renewable energy in integrated systems, forage types [27–31], forest management and integration with other systems, greenhouse gas emissions, water and land usage [11,21,22,32–36] and pasture management [18,19].

This study aimed to analyze the system-specific pillars of sustainability in beef cattle production through an integrative literature review. In the qualitative assessment performed, we used the TBL categories of economic (profit), environmental (planet) and social (people) frameworks for conceptual systematization. We used system-specific categories and subcategories for textual cluster analysis in the quantitative assessment. This study intended to answer the following question: what are the specific challenges and strategies for sustainability in the rapidly growing beef cattle sector in emerging markets and developing economies?

2. The Research Rationale

The sustainable transition of cattle farming in Brazil requires new approaches to biological and predominantly social concerns. To date, research has concentrated on the physiological factors that, e.g., influence cattle distribution patterns on rangelands, but have minimized the social aspects. Despite the strong cattle ranching culture in Brazil, contemporary environmental challenges, consumer preferences and perspectives require biotechnological but also organizational and social improvements that boost transparency and traceability in beef supply chains and market knowledge [37]; financial and managerial efficiency [15]; soil management, in particular, which prevents pasture degradation, habit conversion and deforestation [16]; and human and animal welfare [38,39]. Therefore, in this research, we aim to obtain the most comprehensive view of the social science literature that examines the concept of sustainability in beef cattle production, which has been less studied in livestock science to date.

Psychology, sociology, economics and management play a significant role in building sustainable production models. Nowadays, business and organizational models are based on cooperation, inter-organizational relationships, trust and reputation [39,40]. As research now shows, breeding is not only a biological, but mainly a social phenomenon, which is in line with the post-humanist trend in science. General principles for breeding, genetics, nutrition, reproduction, health, and welfare are similar across livestock species. Still, specific knowledge and management within each species (as well as within combinations of animal resources, production environments, and local markets) are crucial for short-term and long-term economic success [41]. Nowadays, scientists pay attention to human social structures and observe the social behaviors of fauna and flora, e.g., grazing beef cattle. They discuss the implications of social dominance hierarchies and resource abundance for herding and management. Breeders must consider livestock social behavior as effective [42]. Other authors show how the social group influences individual stress responses to fear-eliciting situations in cattle, a gregarious species [43]. The social aspects impact livestock welfare, and cattle pens adjacent to residential areas will affect the quality of water consumed by humans. The economic, environmental, and social implications arising from this transformation are critical to the prospects of the sustainability of this new livestock system and the adoption of interventions [44].

In this study, livestock production sustainability is understood as the combination of economic viability for farmers, environmental soundness and social acceptability by respecting animals and humans. With this meaning, sustainability has become an essential agenda in the development of the livestock world recently, due to the failures experienced in achieving social goals and in the environmental impacts of livestock production development. Meanwhile, the concept of sustainability is dynamic. In other words, sustainable livestock systems in one area will be different from other areas, and a sustainable system at this time will not be sustainable in the future. All of this is due to changes in environmental conditions [44].

This review considers findings in the literature before the COVID-19 pandemic, which dramatically affected the cattle and beef industry, causing massive disruptions in supply and demand for cattle, particularly in the feedlot sector—the one most directly linked to beef processing [45]. Studies referring to a clear description of the relationship between sustainability and beef cattle production are considered suitable for this review. This review aims to discuss the sustainability aspects that appear most frequently in the context of this particular agri-food industry and to synthesize sustainability in beef cattle production.

We used a thematic analysis approach to identify sustainability factors in beef cattle production. The inductive approach was used to establish conceptual paths that answer the research question and to find the main ways of operationalizing sustainability in the selected agri-food industry.

3. Research Methods

We conducted an integrative review (IR) to summarize various studies and better understand the sustainability concept in beef cattle production [46]. We mainly focused on Brazil, being the biggest beef cattle producer among emerging markets and developing countries. We synthesized representative literature on the topic in an integrated way so that new frameworks and perspectives on the topic were generated. We addressed emerging topics that benefited from the conceptualization and synthesis of the literature to date and led to a new system-specific framework of sustainability pillars. The qualitative synthesis holistically addressed the problem. It was performed based on six steps: (i) formulation of the research question, (ii) literature searching, (iii) data extraction, (iv) critical analysis of the included studies, (v) analyzing and synthesizing the results, and (vi) presenting the IR [47,48]. The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) was adapted and used to report this IR since there is not a specific checklist for this literature review method yet [49]. The PRISMA methodology is optimal because both evaluators and readers of the work can identify the paths followed by the authors [50].

We used the most general descriptive terminology that is well embedded in the theory and empirical literature, i.e., 'sustainability'. The selection of papers was based on inclusion and exclusion criteria, which helped to limit the findings to the eligible scope of the social science research, exclusively focusing on an understanding of sustainability in the selected agribusiness sector.

The exclusion criteria comprised: (i) duplicated papers among the search databases; (ii) research on non-social sciences, mainly from the biological sciences; (iii) the application or only the adoption of existing sustainability methods; and (iv) descriptions of tools, indexes or indicators, public policies, environmental efficiency, or environmental impact.

The stipulated period for database search strategies was from 1990 to 2018 since it covers the complete beef cattle and slaughtering cycle (42 months) and market trends before the COVID-19 pandemic outbreak. The multilingual body of literature published after the timeline is not included in this study.

The literature search was performed in the Web of Science, Scopus and Science Direct databases. The general terms "sustainability" and "beef cattle" were searched simultaneously, focusing on each paper's title, abstract, and keywords. As a result, 108 papers were obtained, of which 47 were obtained from Scopus, 36 from Web of Science and 25 from Science Direct. The flowchart of the complete procedure applied is presented in Figure 1.

Systematic review software (StArt) was used to analyze the data and select papers that satisfied the criteria for performing the other phases of the IR. Data from the papers were collected, including authors' names, year of publication, periodicals, abstracts and keywords. It was possible to carry out the planning protocol with selected documents, execute the identification of studies by categories of inclusion and exclusion, and summarize the results. During this stage, based on the title, abstract, keywords and the full text, read by the reviewing authors, the papers not falling within the eligibility criteria were indicated and discussed for exclusion. The list of excluded documents and an indication of the exclusion criteria are presented in Supplementary Materials Table S1.

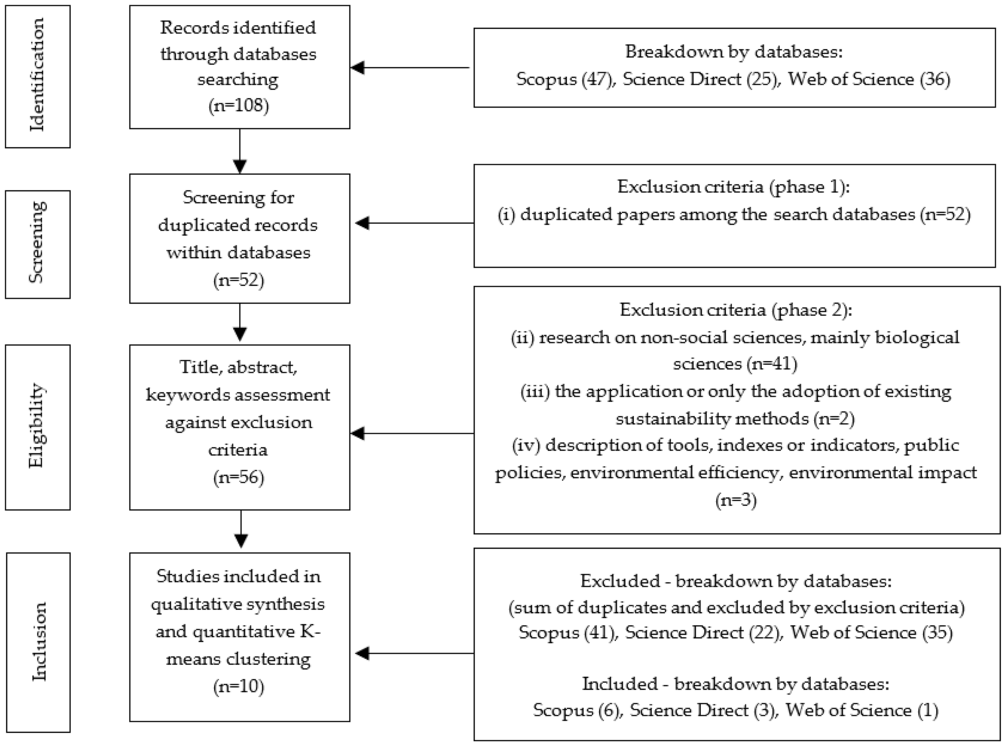

Figure 1. Flow diagram of the integrative review.

The texts were fully read, the main ideas were described, and system-specific categories and subcategories were determined and discussed. Following this, the included papers were used for the qualitative thematic and quantitative cluster analysis resulting in new perceptions about system-specific sustainability in beef cattle production.

In the quantitative analysis, the profiles of the papers and their main trends were identified with the tool of K-means clustering. The determined categories and subcategories were used for cluster analysis of the types in the text of the papers. The information was gathered and organized in a database, where it was analyzed using the machine learning tool of the JASP software, version 0.14.1.0. The K-means clustering is based on an optimization procedure in which data is reallocated between clusters with a partition objective defined as optimal [51]. The Hartigan and Wong [52] algorithm was applied to partition the data space with the sum of squares of the errors (SSE) locally within the cluster. For the silhouette index (which measures the quality of the group), the general rule is that the closer the result is to the upper limit (1), the more consistent the cluster will be, while a result closer to the lower limit (-1) indicates inferior quality [53,54]. The following equations were used in the textual cluster analysis (Table 2).

The 13 research categories that constitute the sustainability context in the beef cattle industry were determined. For this, the researchers' knowledge and the use of these terms in the studied literature were used. These categories were counted in the included papers' abstracts, introductions, results, discussions, and conclusions. The result of the count indicates the frequency of occurrence, i.e., how often a category occurs in a given piece of text. Occurrence is the actual instance in which the category appears. This is a standard procedure for text analysis. It does not aim at sociometric measurement and does not measure the significance.

Table 2. Formulas employed for textual cluster analysis.

Equation	Formulation of the Equation	Variables of the Equation
(1)	$d(P,x) = \frac{1}{n}\sum_{i=1}^{n} d(p_i,x)^2$	x {$x1$, xk} = elements of a set p_i = point of a cluster set d = distance between points n = number of elements
(2)	$SSE2 = \frac{N_i \Sigma_j \lVert x_{ij} - c_i \rVert^2}{N_i - 1} < SSE1 = = \frac{N_1 \Sigma_j \lVert x_{1j} - c_1 \rVert^2}{N_1 - 1}$	SSE = sum of squares errors N_i = total elements of the set X_{ij} = element of the set C_i = centroid
(3)	$S(i) = \frac{b(i) - a(i)}{max(a(i),\, b(i))}$	$a(i)$ = the average distance of data i to all other data in its group $b(i)$ = the minimum distance of data i to all other data that do not belong to its group $S(i)$ = the average of all data in the group

Source: authors' elaboration based on [52,53].

The clusters serve as a convenient data summary, which can be used for further inference. The goal of clustering is to find structures that adequately summarize the data. The purpose of a clustering task is to detect structures in the data. To do so, the algorithm needs to (1) identify the number of structures/groups in the data and (2) figure out how the features are distributed in each group. There are no correct clusters for an unsupervised learning method—only useful ones. One should use the clusters in a follow-up analysis to decide whether the clustering is functional. It was useful if the cluster information helped improve predictions in a follow-up task. With a fixed number of 3 clusters, the K-means algorithm solves an allocation problem; that is, it decides for each of the cases whether it belongs to the cluster "1", "2", or "3".

Two subcategories were established to identify the greater meaning addressed by the documents within the sustainable context. The first subcategory was divided into social, environmental, economic, air pollution, and sustainable production and consumption. The second subcategory was based on the employment of the standard categories of the TBL (3P—planet, people, and profit).

The primary outcome of this study is the qualitative and conceptual reasoning on sustainability in the selected agri-food industry, i.e., beef cattle. However, this study also contributes by using the quantitative K-means method to identify patterns of homogeneity within the studied literature. Finally, the researchers checked the quality of the identified clusters, synthesized emerging research themes and conceptualized a new model of system-specific sustainability pillars in the beef cattle industry.

4. Results

4.1. Overview of the Literature Included

Included studies were conducted in Costa Rica [5], the UK [6], Brazil [17,26,55–57], Spain [58,59], and Canada [60]. Most studies discussed different beef cattle production systems using case study evidence, and only one presented a conceptual review [6]. The main focus of the papers was empirical evidence of sustainability practices or conversions. The theoretical background was rarely discussed widely, even if the authors used academic connotations and categorizations. The papers evidenced economic and environmental impacts. The studied literature discussed different concepts of production systems, management performance, new technologies, and sustainable conversions. Key findings inform various aspects of system-specific sustainability, which led to the determination of system-specific categories and subcategories for the integrative review (Table 3).

Table 3. Descriptive characteristics of the included articles (n = 10).

Author, Year, Country	The Background	The Method(s) Applied	Key Concepts Discussed	Key Findings
Bouman, B.A.M., Nieuwenhuyse A. 1999 [5] Costa Rica	Economic viability	Linear programming	Options for sustainable beef breeding and fattening production systems	Sustainable beef cattle ranching is best realized by integrated intensification that raises total economic returns, i.e., use of grass legumes or fertilized pastures, high feed supplements and improved herd management techniques.
Evans, N. et al., 2003 [6] UK	Biodiversity	Conceptual review	Agri-environmental policy and local expression of agri-environmental priorities and local agri-environmental management	Agri-environmental policy has to enter a new phase in which local conditions and local solutions become more central to the political economy of agriculture. Agri-environmental policy has functioned almost entirely following macro-level principles, primarily because it has to compete with profitable agriculture.
Dick, M. et al., 2015 [17] Brazil	Production systems	Life cycle assessment (LCA)	Environmental impacts of beef cattle production in extensive and improved systems	Strategies to mitigate the possible environmental effects of beef cattle production should focus on productive upgrading.
Picanço Filho, AFP et al., 2009 [26] Brazil	System dynamics	Descriptive	Assessment of economic and financial beef cattle sustainability	The availability of cheap land is a favorable factor for expanding livestock. But there are many challenges to developing beef cattle activities, which has contributed to hampering the sustainability of livestock: (a) farming is carried out on lowland and dry land, most of the times distant from each other; (b) low level of mechanization and technology; (c) high transport costs from the floodplain to the mainland; and (d) the forest code.
Gomes, E. et al., 2012 [55] Brazil	Production systems	Data envelopment analysis (DEA)	Performance of the beef cattle rancher's decisions	Knowledge and process management are the most critical factors for improving the efficiency of beef cattle production systems
Cerri, C. et al., 2016 [56] Brazil	Extensive systems	Case study, descriptive	Evaluation of GHG emissions	Recognition of GHG sources contributes to a greater understanding of environmental impacts and sustainability.
Florindo T. et al., 2017 [57] Brazil	Production systems	LCA (life cycle assessment) and LCC (life cycle costing)	Reduction of GHG emissions and economic viability	Increasing animal production by reducing emissions is a significant technical, scientific and social challenge due to the constant competitive aspects: economic and environmental.

Table 3. *Cont.*

Author, Year, Country	The Background	The Method(s) Applied	Key Concepts Discussed	Key Findings
Escribano, A. et al., 2014 [58] Spain	Organic farming	Cluster analysis	Sustainability typologies	Three types of beef cattle farms were observed in the scores achieved: ecological, conventional and intermediate farms. All farms must act on active measures regarding managing the agroecosystem, competitiveness, business agility, and economic risk.
Escribano, A. 2016 [59] Spain	Organic farming	Index analysis	Feasibility of converting to organic systems	Beef cattle farms must carry out adaptations in all areas of activity to overcome the conversion process, especially concerning health management and the agroecosystem (environmental, ecology principle).
Sheppard, S. et al., 2015 [60] Canada	Management practices	Analysis of variance (ANOVA)	New sustainable technologies	Beef cattle production is key to sustainable food production because it makes productive use of poor-quality land. However, some aspects of beef husbandry affect the impact of beef production on the environment.

Source: authors' study.

4.2. Clustering of the Studied Categories

The most often referred categories (i.e., the most frequent in occurrence) in the studied literature were: '*environmental resources*' (42 references in introductions and 33 in results and discussions sections) and '*emissions*' (15 references in introductions and 102 in results and discussions). Quite often referred to (i.e., quite frequent in occurrence) in results and discussions was also '*carbon footprint*', with 18 references (Table 4). This finding makes it possible to consider that environmental resources, emissions and carbon footprint are the most common sustainability problems in the beef cattle industry.

Table 4. Sustainability category and subcategory references in the studied literature.

Categories	A	I	RD	C	T	PPP
(1) Environmental resources	12.0	42.0	33.0	15.0	Environmental	Planet
(2) Emissions	8.0	15.0	102.0	6.0	Air pollution	Planet
(3) Environmental impact	5.0	12.0	4.0	5.0	Environmental	Planet
(4) Carbon footprint	2.0	0.0	18.0	5.0	Air pollution	Planet
(5) Sustainable economy	1.0	2.0	2.0	1.0	Economic	Profit
(6) Renewable resources	1.0	2.0	1.0	2.0	Social	Planet
(7) Impacts mitigation	1.0	1.0	1.0	2.0	Air pollution	Planet
(8) Sustainable production	1.0	1.0	1.0	1.0	Sustainable production and consumption	Planet
(9) Sustainable beef	1.0	0.0	1.0	1.0	Sustainable production and consumption	People
(10) Sustainable development	0.0	2.0	4.0	1.0	Social	People
(11) Sustainable consumption	0.0	1.0	2.0	1.0	Sustainable production and consumption	Planet
(12) Economic impact	0.0	1.0	1.0	1.0	Economic	Profit
(13) Environmental practices	0.0	0.0	1.0	1.0	Environmental	Planet

Notes: A—abstract; I—introduction; RD—results and discussions; C—conclusion; T—subcategories; PPP—three bottom line (TBL). Source: authors' study.

The homogeneity of the sustainability concept in selected categories and subcategories was analyzed using K-means clustering. The quality of the clusters was assessed by fitting the data to the quantitative model. The model presents the fit scores for the 3 clusters (k = 3) determined for the above dataset with 13 research categories (Table 5).

Table 5. Cluster K-means.

Clusters	N	R^2	AIC	BIC	Silhouette
3	13	0.62246	63.18000	73.35000	0.26000

Source: authors' calculation.

The model presents a good fit. The value observed of R^2 was 0.62246. The Akaike information criterion (AIC) and the Bayesian information criterion (BIC) measure the goodness of fit of a model [53]. The lower the values, the better the quality of the analysis. The silhouette index was 0.26000, presenting a low tendency of grouping clusters because there were no similarities between the categories. This result demonstrates that the reviewed texts show a diversity of approaches to sustainability. Thus, it can be assumed that they provide excellent preliminary material for formulating a complex sustainability model for the beef cattle industry. The following analysis shows the cluster size, the variability in the sum of squares, the proportion of heterogeneity and the silhouette index (Table 6).

Table 6. Cluster information and meaning.

Cluster	1	2	3
Size	6	5	2
Explained proportion within-cluster heterogeneity	0.42925	0.17203	0.39872
Within the sum of squares	11.66823	4.67634	10.83852
Silhouette score	0.19338	0.42187	0.06663
A	−0.35174	−0.39571	2.04450
I	−0.24675	−0.46452	1.90155
RD	−0.38834	−0.30207	1.92020
C	−0.35092	−0.30913	1.82557
T	0.78856	−0.85165	−0.23657
PPP	0.38030	−0.50440	0.12010

Notes: A—categories in the abstract; I—categories in the introduction; RD—categories in the results and discussion; C—categories in the conclusions; T—subcategories; PPP—triple bottom line. Source: authors' calculation.

The clusters of referred categories have different sizes. Cluster 1 (the largest) embraces 6 out of the 13 determined categories: (3) 'environmental impact', (5) 'sustainable economy', (6) 'renewable resources', (10) 'sustainable development', (12) 'economic impact', and (13) 'environmental practices'. It is the most heterogeneous, with a proportion of 0.42925. Cluster 2 (slightly smaller) groups 5 categories out of 13 determined categories: (4) 'carbon footprint', (7) 'impacts mitigation', (8) 'sustainable production', (9) 'sustainable beef', and (11) 'sustainable consumption', with an index of 0.39872. Cluster 3 (the smallest) consists of two categories: (1) 'environmental resources' and (2) 'emissions'. It has a greater homogeneity, with an index of 0.17203. This is due to the number of times the two categories actually occur, as they were the most frequently referred to by the authors and the most relevant in this context.

The first cluster embraces general economic–environmental categories from the field of sustainability, with an utmost academic focus. The second cluster includes categories related to sustainable production and management processes. The third, meanwhile, relates directly to significant impacts of an environmental nature. When analyzing the sum of squares, cluster 2 is considered more compact. The categories that compose it are mentioned in similar quantities. This is primarily due to the empirical scope of the analyzed studies, which mainly use the case study method. On the other hand, clusters 1 and 3 are more heterogeneous. The higher values represent more variability of observations within the clusters. The silhouette index demonstrates homogeneity and cohesion, and the best results were found for cluster 2, with 0.42187. Cluster 1 presented 0.19338, considered low, and cluster 3 (two observations) was 0.06663, demonstrating that they are heterogeneous. This is because 'emissions' relate directly to animals, while 'environmental resources' pertain mainly to land use as pasture. So, in the case of categories in Cluster 3, heterogeneity is justified by the subject matter and homogeneity by the frequency of the actual occurrence the categories.

It was also found which variables contributed the most to the grouping. Cluster 1 was influenced mainly by the subcategories (T), with a value of 0.78. The PPP (triple bottom line), A (categories in the abstract), I (categories in the introduction), RD (categories in the results and discussion), and C (categories in the conclusion) are balanced—demonstrating that the occurrence of words was balanced for this cluster. Cluster 2 was influenced by subcategories (T) with a value of −0.85165 and PPP (triple bottom line) with −0.50440. Meanwhile, cluster 3 was determined by A (categories in the abstract) with 2.04450, I (categories in the introduction) with 1.90155, RD (categories in the results and discussion) with 1.92020, and C (categories in the conclusion) with 1.82557. It is worth noting that all the examined values are high because they represent terms widely used in all the studied texts. It was also possible to observe the midpoint and scope of each cluster and its relationship with each variable (Figure 2).

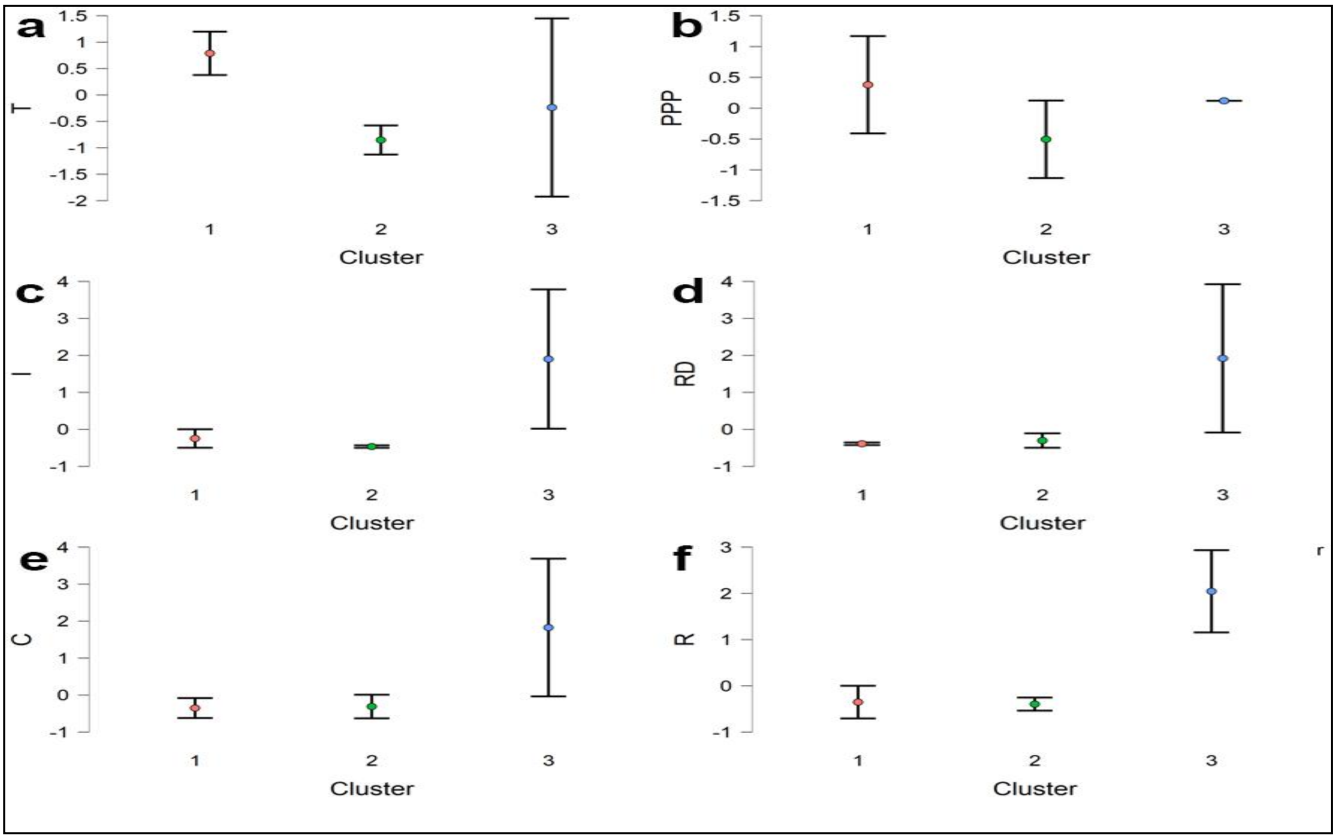

Figure 2. Interval graphics refer to the number of categories found in the papers. Notes: (**a**) T (subcategories); (**b**) PPP (triple bottom line); (**c**) I (categories in the introduction); (**d**) RD (categories in the results and discussion); (**e**) C (categories in the conclusion); (**f**) A (categories in the abstract). Source: authors' calculation.

Part (a) represents the subcategories (T) graphic, where the categories were classified by similarity. Cluster 3 has a high amplitude concerning the average and is formed by subcategories such as 'air pollution' and 'environmental'. Clusters 1 and 2 have low amplitude concerning the average. Part (b) presents the relationship between the categories and the triple bottom line (TBL). Clusters 1 and 2 have similar amplitudes as they are composed of a great diversity of categories and have high amplitude concerning the average. Parts (c), (d), (e), and (f) are related to the quantification of categories in different parts of the papers, demonstrating how the discussion was developed within the reviewed body of the literature. Clusters 1 and 2 have some similarities concerning average: both have lower values and low amplitude, meaning a low variability of categories in the papers. Cluster 3 (composed of two categories) is characterized by high average values and large amplitude, confirming that these terms primarily influence the context of sustainability in beef cattle production. We also visualized the densities of the clusters for each variable (Figure 3).

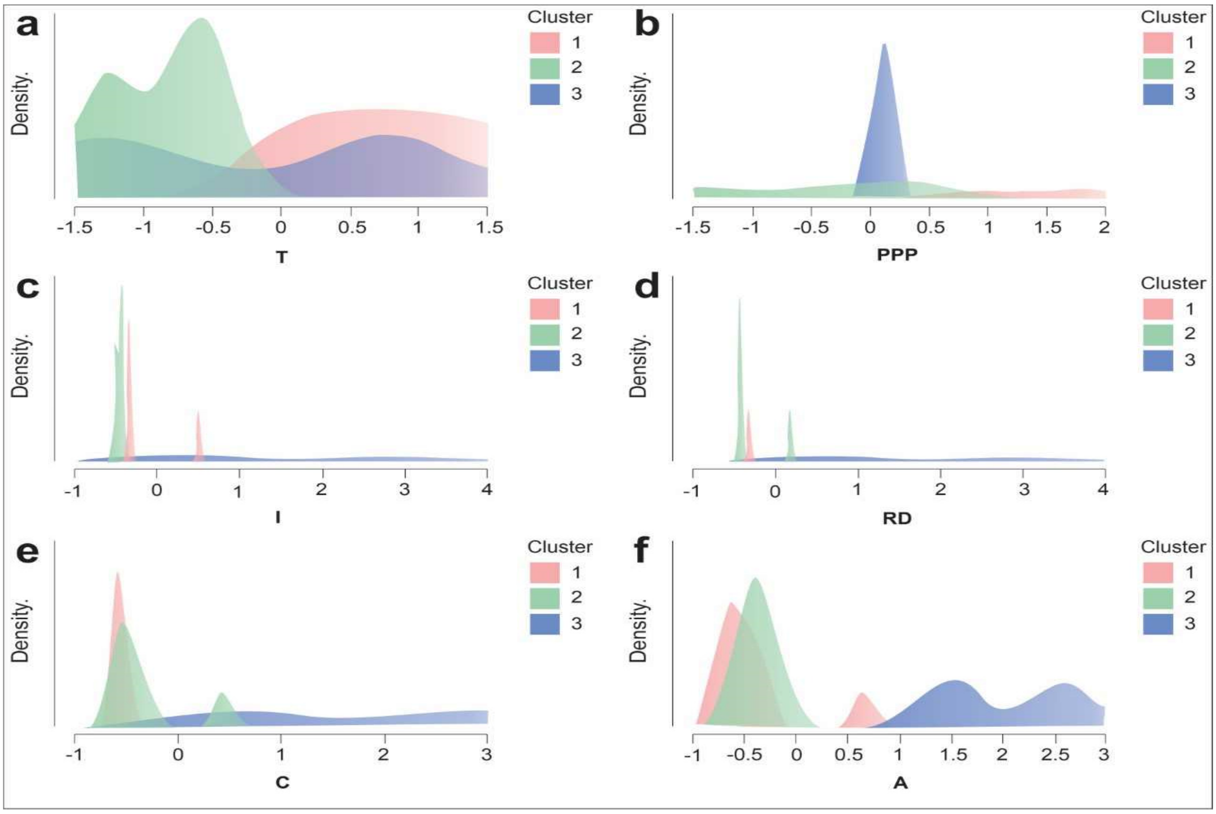

Figure 3. Density graphs refer to the number of categories present in the parts of the papers. Notes: (**a**) T (subcategories); (**b**) PPP (triple bottom line); (**c**) I (categories in the introduction); (**d**) RD (categories in the results and discussion); (**e**) C (categories in the conclusion); (**f**) A (categories in the abstract). Source: authors' calculation.

When comparing the parts of the texts analyzed, the highest frequency of categories occurred in the results and discussions parts, followed by the introductions, conclusions, and abstracts. The lower variability between clusters occurred in the abstracts. The main results were about subcategories (T), which showed the influence of all clusters, and the triple bottom line (PPP), which showed the more substantial effect of cluster 3 ('emissions' and 'environmental resources'). When overlaps occurred, this is reflected in the apexes of each of the variables captured in each cluster. In the density graphs presented for the subcategories variable (T), cluster 2 presents a density peak that is concentrated at the -0.5 level. For the TBL (PPP) variable, cluster 3 presents a density peak between levels 0 and 0.5. For variable I (categories in the introduction), RD (categories in results and discussion), C (categories in the conclusion), and A (categories in the abstract), clusters 1 and 2 show a density peak between levels -1 and 0, demonstrating similarity between clusters.

To conclude, the textual clustering of categories and subcategories led to the determination of the system-specific categories occurring in the literature on beef cattle industry sustainability, which identified the main socio-economic research areas of sustainability for the beef cattle industry in the preliminary empirical literature to date. These are sustainable development, sustainable production and sustainable environmental impacts. These quantitatively identified research areas will serve as a first step in the new system-specific conceptualization of sustainability in the beef cattle industry. The next step of the review is the thematic synthesis of the findings and conceptualization of a new model of system-specific sustainability pillars, which will be developed in the discussion part of this review.

5. Discussion

5.1. Thematic Synthesis

We carried out an in-depth qualitative analysis of the eligible texts to address emerging topics that would benefit from a holistic conceptualization and synthesis of the literature to date. Because the topics are relatively new (mainly empirical case studies) and have not yet undergone a comprehensive review, this was likely to lead to an initial conceptualization of the topic, i.e., a new analytical framework of system-specific sustainability pillars. The analysis resulted firstly in the thematic synthesis. Some of the themes, like the categories and subcategories analyzed, were identified in more than one text, and in some cases, more than one theme could be discussed in one paper. We identified six emergent research themes on sustainability in the beef cattle industry (Table 7).

Table 7. Emergent research themes on sustainability in the beef cattle industry.

Theme		Main Focus
(1)	Implementing integrated systems	Use of resources in integrated production
		Integrating production such as milk and beef
(2)	Implementing standardized systems	Focus on using standard variables that provide a scenario with comparable results between different systems and regions of the country
		Determine changes to the quantitative calculation of resource use by beef cattle production to create a standard analysis method
(3)	Considering regional singularities	Understand the regional diversity related to the measures used to mitigate production impacts
		Determine how environmental production can be implemented considering regional singularities
(4)	Employing technology and science	Lead the sustainability of beef cattle production, considering technique, science and social aspects
		Discuss alternatives that adopt available technologies to improve production processes with less impact
(5)	Benchmarking and promoting	Promote the best existing beef cattle production systems that have lower environmental impacts
		Analyze organic beef cattle livestock good practices and variables that can be sustainable examples to other systems
(6)	Embracing new aspects	Evaluate carbon capture possibilities with technique, science and social concerns to achieve sustainability
		Discuss approaches beyond environmental, economic and social aspects

Source: authors' elaboration.

(1) Implementing integrated systems

Beef cattle livestock have been studied over the years to mitigate their environmental impacts. Sustainable systems with returns are adopted mainly with intensified integration of improved herds with high growth rates, sustainable grasslands with high yields of food quality and high levels of food supplements [5]. Meanwhile, cleaner production practices can be used as a management strategy, emphasizing the conscious use of water, which can be implemented in dry cleaning systems, operational control and reuse practices. The same deliberate use can be applied to electricity obtained from renewable sources [57].

The use of resources, such as land, is a factor that contributes to the expansion of production activities. In countries with large territories, like Brazil, land costs are low. The difficulties in developing sustainability-oriented activities emerge in lowlands and property lands, which may be distant from one another and hinder the management of animals; high transport costs between these locations; and forest legislation codes that determine the containment of deforestation. This is so in the Brazilian case [55]. This approach corroborates the background in which the link between different integrated production systems is critical for discussions on sustainability [21].

Achieving sustainability has been a challenge for beef cattle ranchers, especially in the sense of the resilience of the farm. It includes transformations to enhance global change levels and farmers' values [25]. Some systems impose stress on the environment, such as the cropping system. These systems make production unsustainable, in contrast to integrated systems with higher profitability and less environmental impact [24].

(2) Implementing standardized systems

Beef cattle production occurs in different regions, and regionality reflects various production systems. It leads to multiple levels of use of natural resources, as well as the existence of various profiles of producers and properties. It also reflects the different economic conditions of the regions. In this sense, natural resources play a fundamental role in classifying the various systems, which may be a basis for suggesting public policies related to sustainability [58]. Some regions adopt integrated systems and can potentially reduce global problems such as the environmental footprint of food systems [24]. Other concerns, such as water consumption, cattle welfare, and energy approaches, are in vogue [29,61–63]. The intensification of grassland-based production (with more technology) can reduce the sustainability of the production system. This is because this production system uses more natural resources than other systems. Thus, adaptive changes must be implemented to maintain the ecosystem. This shows the need for improvement in agroecosystem management, which can increase competitiveness and commercial agility and reduce economic risk [60]. This proposal is linked with the idea of using integrated models to project scenarios to a national level, which includes the use of geographical databases with variables that support sustainable analysis [3].

(3) Considering regional singularities

The need for competitiveness faces regional differences and barriers. Regional differences are emphasized as factors that influence the use of natural resources such as land [56]. Changes can improve efficiency and productivity in management. More competitive production could occur with adjustments in forage quality by strategic fertilization, reduction of methane gas emissions by reducing the maturation of forage during harvesting, and protection of storage to avoid losses, including nutrients [60].

There are strategies for adjusting the impacts of beef cattle production and product improvement as the primary focus. It has been proposed that grasslands be improved for extensive systems, whereas intensive systems can be developed by producing many tropical forage species and practicing more intensive pasture rotation. This improvement can mean better environmental performance for intensive systems for meat production [18].

The source of impact needs to be understood so that mitigation projects with improvements in production can be implemented. Animal waste management, for example, can be used in extensive systems to reduce one of the emission sources. However, the results obtained in specific cases cannot be generalized to other regions with different climatic conditions at the place of production, pasture management, and characteristics of animal productivity. These aspects make comparisons between the applied studies and the purpose of other productive alternatives that mitigate impacts even more complex [18,59]. Even with insufficient levels of climate efficiency, farms are improving and becoming more sustainable [25]. Several possible mitigation solutions include beef cattle integration with other productions, beef traceability, and alternative feedstuffs [23,28,64].

(4) Employing technology and science

To reduce the diversity of externalities and production vulnerabilities, adaptations should be made regarding management health, and on the agroecosystem concern (analysis based on environmental and ecological principles), the adaptations are on the social aspect of sustainability. The self-confidence of farms should be increased to improve economic results based on the changes proposed to achieve sustainability. This improvement leads to ecological solidity concerning the nutrients used and agrobiodiversity [57]. This is due to the role played by various agents such as governments, universities, industrial sectors, companies, and society to guide sustainability [7].

The improvement of production and the reduction of emissions have challenges that involve technique, science and social aspects. These drivers are involved with competitive elements that result in economic and environmental analysis [65]. However, there are few studies on the impacts caused by production and mitigation regarding beef cattle production [66]. A better understanding of technologies can be an alternative to using natural resources in production, thereby reducing the impacts caused [67].

Although intensive systems use more land resources, they have the potential to remove carbon from biomass and the soil [17]. In this case, grazing and feeding practices are essential to achieve better results [68]. It leads to a synergy between industries, design, and production management [69].

(5) Benchmarking and promoting

The organic beef cattle production system adjusts to local production conditions and replaces chemical inputs with organic, biological and ecological inputs [70]. This can be a means of bringing all theories together with possible actual practice. The replacement of chemical information with organic inputs is a decision that leads to sustainability. Reducing methane gas emissions is one of the objectives of organic production, which uses animal productivity improvement studies, better feed quality, levels of soluble carbohydrates in the animals' diets, and additives that alter fermentation during rumination [71]. Another highlight is the difference between intensive and extensive systems. Although intensive systems tend to reduce greenhouse gas emissions, they consume significantly more energy [18]. Nevertheless, the intensive beef cattle production system avoids negative impacts such as deforestation [19].

Promoting the use of local resources and natural allopathic treatments in the cattle production process is beneficial to all the products generated. The focus is the exchange of supplement concentrate through ingestion during soil grazing. The counterpart of organic production is a good reception by consumers, but at prices generally higher than traditional production [72].

(6) Embracing new aspects

Regarding production improvements, a concept for neutralizing emissions from the integration of production components has been developed. It is an integration of livestock–forest systems (or silvopastoral) and farming–livestock–forest systems (or agrosilvopastoral) [73,74]. The carbon-neutral meat (CNM) concept has the potential to contribute to sustainability studies that aim to mitigate the impacts caused by economic activities. In this case, the technologies for intensifying and implementing integration systems are available for all regions and their individual ecosystems [74]. However, the issue to be addressed is the relationship between production performance and emissions [75].

Programs such as organic beef cattle production have positive and competitive results for cattle production as they can facilitate the diversification of production methods and increase productivity [76,77]. As a certain amount of carbon is emitted in feedlot manure handling systems, cattle diets and feed activities, these areas are the priorities of recent studies [73,78].

5.2. A New Framework for the Topic

The clustering of sustainability categories and subcategories and the thematic synthesis of the literature led to the identification of new relationships and perspectives on sustainability in the beef cattle industry and yielded a new conceptual framework proposing new pillars of system-specific sustainability [47,48,79]. Based on the knowledge collected, it was possible to understand better the relationships between the beef cattle industry and the objective of assisting in the search for sustainability. The principle of support of multiple disciplines is used for the present context [77]. The beef cattle industry is a complex production system with different applications depending on the regional location of production, the selected production systems, and the characteristics of each entity and producer. The sustainability of the system can be determined by the feeding system and animal husbandry, with different factors such as soil use, type of interaction with the grassland and the use of confinement in the rural property. These characteristics make it challenging to study the determining factor of environmental sustainability of production.

In Brazil, beef cattle farming has three stages of production: breeding, rearing, and finishing. The three phases can be carried out on the same farm (full cycle) or different farms (partial cycle). Brazil's beef cattle production systems comprise cow-calf; cow-calf and backgrounding; cow-calf, backgrounding, and feedlot; backgrounding and feedlot; and feedlot. The beef cattle production chain includes several stages of animal raising and fattening and involves multiple intermediaries. In addition to the direct purchases of calves and lean cattle from breeding and rearing farms, cattle transactions along the supply chain may involve other avenues, such as auctions and transactions between producers using the same system, among others. In other words, for each direct supplier, there may be several indirect suppliers. Brazil's meat industry features complex business relationships, sometimes marked by distrust. This complexity substantially limits a more comprehensive system to track the entire meat supply chain for providing visibility over the entire system and socio-environmental monitoring [80].

Like other industries, the beef cattle industry is subject to environmental regulations and growing social challenges. Properly designed environmental standards can trigger innovations that lower the total cost of the product or improve its value. Environmental improvement can benefit resource productivity, and process benefits have been reported [81]. The beef cattle industry also undergoes wastage-related losses in natural resources (e.g., water and energy) and feed losses when storing and packaging [82]. Contradictory environmental phenomena are also being reported in this industry.

The rising global demand for animal protein is intensifying livestock production systems. At the same time, societal concerns about sustainability and animal welfare in intensive systems are increasing [38]. On the other hand, most Brazilian beef exports are live animals or raw meat, i.e., low-value-added exports, leaving little room for investments in productivity and the environment. Low-tech and extensive cattle ranching systems and investing little in land and pasture care or animal husbandry lead to pasture degradation. Inadequate soil management and low productivity will inevitably lead to more deforestation [16]. Unless Brazil's beef industry can transition from low-productivity, extensive ranching to more sustainable and intensified ranching, increasing production to meet rising demand could only be addressed by expanding the area for raising cattle, at the expense of the Amazon forest, which would not be acceptable to the global community. Adverse environmental effects of deforestation include biodiversity loss, land degradation, and increased emission of trace and greenhouse gasses. On the one hand, large tracts of forests have been cleared and converted into pastures for beef cattle ranching. On the other hand, pasture management for beef cattle ranching is typically extensive, with low external inputs and zero fertilizer use [5].

Developing a more transparent supply chain in the Brazilian beef sector is a complex endeavor, requiring collaboration among all stakeholders in the beef and leather value chains, along with crucial support from government agencies. Without this support, deforestation caused by cattle farming is unlikely to decline. This process requires integrating cattle farming with crops, controlling the stocking rate (the number of animals per grazing area), engaging in regular analysis and correction of soil fertility, controlling weeds and pests, and rotating animals to allow pastures time to recover. Coordinating this with better genetics, more sustainable practices, improved soil and animal welfare, and easier access to water, cattle will grow faster—and younger cattle generate higher-quality beef and less carbon dioxide per kilogram of beef, leading to higher returns for producers. Because of their access to data from cattle producers, meat processors are in an ideal position to play a crucial role as they work with suppliers to establish a supply chain free of deforestation. Three large processors (JBS, Marfrig and Minerva) lead the market; the rest is more fragmented, adding complexity and making engagement more challenging. Meat packers can already trace the origins of their supply using a few available tools, but most of these fail to reach the level of indirect suppliers, where much of the deforestation occurs [16,39].

The complexity of the economic, environmental and social relationships in agri-food sectors, like beef cattle [83], needs expanding and holistic approaches beyond TBL modelling. The textual clustering and synthesizing thematic review of the representative literature on sustainability in beef cattle production generated knowledge for a new perspective. This integrative review addressed new ways of holistic and expanded thinking about system-specific modelling of sustainability. Against this background, we developed a new framework to clarify the approach to the sustainability of the beef cattle industry (Figure 4).

This conceptual reasoning should be regarded as a part of the TBL model. The economic (profit), environmental (planet), and social (people) aspects commonly identified as the TBL have competitive issues involving the first two, i.e., economic (profit) and environmental (planet), also when studying beef cattle [77]. The prevailing view is that an inherent and fixed trade-off is regarded as competitive: ecology (planet) versus the economy (profit). On the one hand, social (people) benefits arise from strict environmental standards and continue as a challenge. On the other hand are the industry's prevention and cleanup costs that may lead to higher prices and reduced competitiveness [81].

Hence, the system-specific approach to sustainability needs to be extended because technology, products, processes and customer needs are not fixed. These entities operate in a dynamic competition, pushed and pulled to find system-specific innovative solutions. The expanded system-specific framework can trigger properly designed environmental and social standards, which stimulate innovations [81]. For these reasons, the TBL model should be extended with the pillars representing dynamic competition, i.e., technique (technological improvements), science (product and process improvements) and social (customer improvements). Since the literature review showed that the challenging pursuit of sustainability in the beef cattle industry relies on technique, science and social aspects, they should constitute the main pillars for integrated economic and environmental analysis of social challenges. The main conclusion of the qualitative review may be the starting point for particular conceptual developments in sustainability that consider the peculiarities of agri-food industries and producers to promote an integrated economic and environmental analysis model that also absorbs the social perspective.

Thus, we developed a new theoretical framework of sustainability extended to beef cattle production. The general framework of the TBL sustainability concept is not contradictory to an integrated economic and environmental analysis in the main areas of development, i.e., technique, science and society. Since the clustering textual analysis findings show the utmost concern on economic–environmental categories in the beef cattle industry (cluster 1), then production and management processes (cluster 2) and environmental impacts (cluster 2), the expanded framework of sustainability in the beef cattle industry focuses on the economic–environmental trade-offs. The thematic synthesis determined the main areas of innovation in the implementation of integrated and standardized systems.

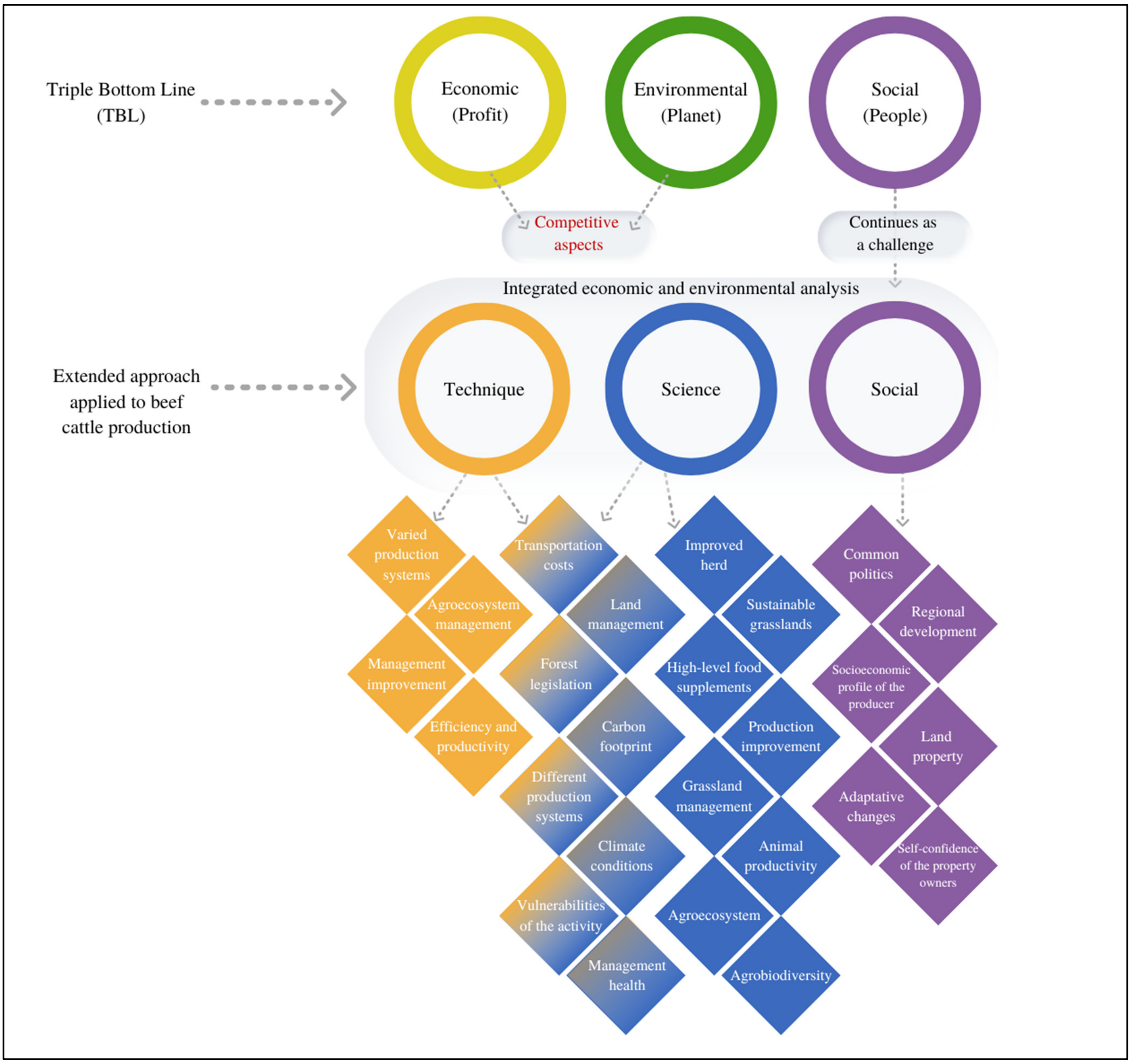

Figure 4. System-specific sustainability pillars for beef cattle production. Source: authors' elaboration.

The thematic synthesis pointed to the priority of technology and science for the sustainable development of production systems in the beef cattle industry, i.e., theme (4) employing technology and science. Therefore, the system-specific sustainability pillars for beef cattle production point to technique and science as primary competitive aspects in the beef cattle industry and make the most of the concept (the yellow and blue themes). It is worth noting that the pillars of technique and science are strongly intertwined, remaining in mutual dependence, as indicated by the intermingling of yellow and blue colors.

Beef cattle producers use technologies to improve animal performance and well-being and increase their enterprises' profitability. The use of technologies in the beef industry is a major contributor to the safe, wholesome, and affordable beef supply [84]. Nowadays, most improvement opportunities lie in new ideas and technologies to develop management practices, accuracy, and methods. Digital technologies may provide direct support for beef cattle producers. Several digital technologies are available for different animal species and form the basis for precision livestock farming. There are several possible digital improvements for cattle producers: using sensors for virtual herd tracking, promoting farming through virtual reality, nutrigenomics creating the opportunity for precision nutrition, drones helping to manage feedlots and ranches, robots performing daily feeding, blockchains offering traceability along the entire supply chain, artificial intelligence (AI) analyzing animals and market data for predictions, and augmented reality enhancing the vision to make better management decisions [85].

Since the social aspects have been less discussed in the literature, they are still challenging themes in the beef cattle industry (the purple themes). Societal concerns should be regarded as emergent themes in beef production in Brazil and other developing and emerging economies. During the COVID-19 pandemic, public and consumer sensitivity to the issue of healthy food produced under socially responsible conditions increased. However, this does not change the fact that Brazilian beef cattle production lacks societal responsibility, which our research confirmed. It was one of the most important reasons for the declining profitability of the top Brazilian meat producers until 2018 [16] (p. 7). Already at that time, consumers demanded high-quality products that were free of deforestation and social abuse impacts [39]. In global markets, demand for non-sustainable beef products was declining, resulting in lower exports and export pricing of Brazilian beef products, particularly in the EU and other overseas markets [16] (p. 2) and [37].

Therefore, social themes are minor and, consequently, still the most challenging part of the concept. However, it seems that with the fulfilment of technical and scientific conditions, society will become the beneficiary of innovative environmental solutions in the beef cattle industry. Within the technical aspect, the theoretical models found can be adjusted to discuss the production systems used differently by beef cattle ranchers. Several studies highlighted management theory and its importance as a strategy that aims at efficiency and productivity, intending to achieve sustainability [58–60]. Economics and environmental analyses using techniques and science transform the state-of-the-art into applied science. Each interconnection shows new perspectives to researchers, including theoretical aspects that can be used as indicators to compare entities. Results have been found linking technique and science to cost analysis related to transport and land, their management and aspects of forest legislation involving production. The production can be seen in terms of improvement of the herd, connecting it to sustainable grasslands and the food supplements used [5,18,55].

From the intersection between technique and science, it is possible to discuss findings of the carbon footprints of production in different production systems. This relationship is based on the results of climate change, which may be a search input for better pasture management and better animal productivity [4,59]. The technique and science aspects make it possible to achieve new steps in standardizing production systems. Extensive, semi-extensive and intensive systems have different levels of carbon footprints owing to their further use of natural resources. The same will happen when future work analyzes interconnections to determine better rural property management.

The social aspect comprehends standard policies among productive activities related to the development of a specific region [58]. This reasoning can include determining characteristics such as land, property, and the social and economic profiles of the producer in the environment. Seeking changes to adapt to the new techniques and scientific discoveries of beef cattle production can be relevant in increasing the self-confidence of the property owners. The literature highlights property owners' social characteristics as aspects of human beings [6,58–60].

The framework may also guide sustainable beef supply chain management. A focus on supply chains is a step towards the broader adoption and development of sustainability since the supply chain considers the product from the initial processing of raw materials to delivery to the customer. It will become increasingly necessary for beef production systems to be structured for increasing traceability and bio-economical efficiency, decreasing environmental degradation [20], and expanding the use of renewable energy and energy efficiency upgrades throughout the entire supply chain [86].

However, each stage of the beef cattle supply chain faces different improvement opportunities. Cow-calf operators, who are the leading investors in depreciable assets and generate revenue from the breeding stock's offspring [45], should be concerned with integrated ranch management planning, optimized grazing and forage improvement, grazing land improvement, and improved wildlife habitat. Stockers, backgrounders, and feedlot producers, who regularly purchase cattle to sell the same animal later [45], face other improvement opportunities. Stockers and backgrounders should be concerned with feed additives and supplemental nutrition to reduce methane production and increase digestive efficiency. Feedlot producers should be concerned with feed additives, feed composition, manure management and reuse [86].

Beef producers need to have a comprehensive understanding of many factors if they wish to build and maintain a successful, sustainable business, including: sustainable pasture management; maintenance of biodiversity; soil and water management; the minimization of greenhouse gas emissions, offensive odors and dust; the efficient use of other resources such as fuel; good stock management, that considers animal welfare; responsible use of chemicals; property management planning, including good risk management with enterprise flexibility that enables adaptation to changing markets; good monitoring and recording systems which gather useful information about the enterprise and allow assessment of financial and environmental sustainability; good community relationships and perceptions; and air management [87].

The newly developed framework helps to overcome the omissions and deficiencies identified in the literature. The main one is the lack of theoretical and holistic approaches, since the up-to-date literature on sustainability in the beef cattle industry relies on empirical case studies that rarely refer to the theory of sustainable development. The topic is relatively new and the literature has not been comprehensively reviewed or confronted with industrial views such as resource-based theory (RBT) or sustained competitive advantage (SCA), nor sustainability concepts such as the triple bottom line (TBL). Moreover, the newly proposed model includes important theoretical issues hitherto overlooked regarding industrial competitiveness and the interchangeability (trade-offs) between economics and ecology. These trade-offs call for an interdisciplinary approach in the social sciences, which should be considered more in sustainability research. As our study showed, most literature treats non-economic and non-social issues by focusing on fields such as biology. This contributed to the exclusion of most studies, as they did not consider economic and social aspects. Thus, the new model should lead to a broader interest among researchers in economic–environmental–social trade-offs in planning research on the sustainable development of agri-food industries, like the beef cattle industry [88,89]. This integrative literature review is expected to also play an essential role in stimulating further research on the topic since it shows new relationships and perspectives that have not yet been fully explored. The latest research questions arising from this integrative review can be formulated as follows: Will the sustainable production and consumption of beef cattle make the industry more competitive? Will environmental improvement benefit resource productivity? Does reducing environmental impact lead to innovation in the beef cattle industry?

6. Conclusions

The sustainable development of the booming agri-food industries in emerging markets and developing countries is becoming today's most prominent economic, environmental and social challenge. Arguably, the outbreak of the COVID-19 pandemic has had a significant impact on consumer concerns and will accelerate the implementation of sustainable models in animal husbandry, including beef cattle farming, particularly in risk management. However, the literature in this area weakly references the social sciences, relying more on the biological and technical sciences. Therefore, there is an ongoing need for literature reviews to develop expanded, holistic sustainability concepts for agri-food industries, taking into account their specificities and developing social and economic aspects of sustainability. This review has filled this research gap for the beef cattle industry by critically and thematically reviewing the literature, setting a new conceptual framework, and expanding the guiding sustainability theory of TBL into the complex concept of the three system-specific pillars of sustainable development in the beef cattle industry. The procedure and the framework can be further extended and evaluated for other agri-food sectors.

The new sustainability framework should be regarded as the direct result and contribution of this review. However, this review has also contributed methodically by proposing the textual clustering analysis of the main categories and subcategories of the topic in connection to the guiding theory, followed by thematic synthesis. This quantitative–qualitative procedure of conducting an integrative review led to more effective identification of homogeneity/heterogeneity in studies to date and more effective recognition of the research gaps. It also led to proposing a new research framework and posing important questions for future research.

This study's main limitation was the small number of studies conducted to date in the area under investigation within the social sciences, including economics. Therefore, the authors of this review hope to further use and develop the proposed concept in the social sciences. This is why the research questions that result from this study should be used in the first place. The proposed research framework should be of particular interest to researchers dealing with rapidly growing emerging markets and developing countries, as the dynamics of these economies, in particular, are associated with the intensification of natural resource use, their frequent degradation and the increased carbon intensity of developing industries, including agri-food industries in particular. The example of the beef cattle industry in Brazil indicates this.

This review should have theoretical, managerial and political implications. Theoretical implications were found with the new conceptual framework. The most relevant and significant is combining environmental, economic and social aspects with technique, science and social factors to achieve sustainability. The managerial implications are connected with guiding the technical and scientific analysis of processes, implementing innovative practices and focusing on the owner's social features, which trigger cooperation and open innovativeness. The political implications are mainly connected with the need for adequately designed regulations with a competitive impact that stimulates environmental innovations.

For this information to lead to adjustments in future decision-making by producers in Brazil, the drivers selected and their future implications are crucial. This contribution may lead to public and private policies to improve productive activity to improve all the technical, scientific and social aspects presented. Future studies can consider this research for application and differentiation between countries, regions, and production systems.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15054670/s1, Table S1: Ineligible literature for the review.

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References

1. IMF. *World Economic Outlook: Countering the Cost-of-Living Crisis*; International Monetary Fund (IMF): Washington, DC, USA, 2022.
2. OECD-FAO. *Agricultural Outlook 2020–2029*; OECD-FAO: Paris, France, 2020. Available online: http://www.fao.org/documents/card/en/c/ca8861en (accessed on 11 June 2021).
3. Ruviaro, C.F.; Léis, C.M.; Lampert, V.N.; Barcellos, J.O.J.; Dewes, H. Carbon footprint in different beef production systems on a southern Brazilian farm: A case study. *J. Clean. Prod.* **2015**, *96*, 435–443. [CrossRef]
4. Dick, M.; Silva, M.A.; Dewes, H. Mitigation of environmental impacts of beef cattle production in southern Brazil–Evaluation using farm-based life cycle assessment. *J. Clean. Prod.* **2015**, *87*, 58–67. [CrossRef]
5. Bouman, B.A.M.; Nieuwenhuyse, A. Exploring options for sustainable beef cattle ranching in the humid tropics: A case study for the Atlantic Zone of Costa Rica. *Agric. Syst.* **1999**, *59*, 145–161. [CrossRef]
6. Evans, N.; Gaskell, P.; Winter, M. Re-assessing agrarian policy and practice in local environmental management: The case of beef cattle. *Land Use Policy* **2003**, *20*, 231–242. [CrossRef]
7. Almeida, C.M.V.B.; Agostinho, F.; Giannetti, B.F.; Huisingh, D. Integrating cleaner production into sustainability strategies: An introduction to this special volume. *J. Clean. Prod.* **2015**, *96*, 1–9. [CrossRef]
8. *Cadeia Produtiva da Carne Bovina: Contexto e Desafios Futuros*; Brazilian Agricultural Research Corporation, Embrapa: Brasilia, Brazil, 2021. Available online: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/224434/1/DOC-291-Final-em-Alta.pdf (accessed on 15 July 2021).
9. Caniglia, G.; Schäpke, N.; Lang, D.J.; Abson, D.J.; Luederitz, C.; Wiek, A.; Laubichler, M.D.; Gralla, F.; von Wehrden, H. Experiments and evidence in sustainability science: A typology. *J. Clean. Prod.* **2017**, *169*, 39–47. [CrossRef]
10. Elkington, J. *Cannibals with Forks*; Makron Books: São Paulo, Brazil, 2001.
11. Nguyen, T.L.T.; Hermansen, J.E.; Mogensen, L. Environmental consequences of different beef production systems in the EU. *J. Clean. Prod.* **2010**, *18*, 756–766. [CrossRef]
12. Mirek, Z.; Witkowski, Z. Theory and practice in nature conservation–Where to seek sustainability? *Pap. Glob. Chang. IGBP* **2017**, *24*, 67–82. [CrossRef]
13. Ramos, A.R.; Ferreira, J.C.E.; Kumar, V.; Garza-Reyes, J.A.; Cherrafi, A. A lean and cleaner production benchmarking method for sustainability assessment: A study of manufacturing companies in Brazil. *J. Clean. Prod.* **2018**, *177*, 218–231. [CrossRef]
14. Wiśniewska, J. Economic sustainability of agriculture–conceptions and indicators. *Acta Sci. Pol. Oecon.* **2011**, *10*, 119–137.
15. Whelan, T.; Zappa, B.; Zeidan, R.; Fishbein, G. How to Quantify Sustainability's Impact on Your Bottom Line. *Harv. Bus. Rev.* 2017. Available online: https://hbr.org/2017/09/how-to-quantify-sustainabilitys-impact-on-your-bottom-line (accessed on 12 January 2023).
16. Libera, C.; Marote, S.; Horta, A.L. *Brazil's Path to Sustainable Cattle Farming*; Bain&Company, Inc.: Boston, MA, USA; The Nature Conservancy: Arlington County, VA, USA, 2020. Available online: https://www.bain.com/insights/brazils-path-to-sustainable-cattle-farming/ (accessed on 12 January 2023).
17. Dick, M.; Silva, M.A.; Dewes, H. Life cycle assessment of beef cattle production in two typical grassland systems of southern Brazil. *J. Clean. Prod.* **2015**, *96*, 426–434. [CrossRef]
18. Ogino, A.; Sommart, K.; Subepang, S.; Mitsumori, M.; Hayashi, K.; Yamashita, T.; Tanaka, Y. Environmental impacts of extensive and intensive beef production systems in Thailand evaluated by life cycle assessment. *J. Clean. Prod.* **2016**, *112*, 22–31. [CrossRef]
19. Figueiredo, E.B.; Jayasundara, S.; Bordonal, R.O.; Berchielli, T.T.; Reis, R.A.; Wagner-Riddle, C.; La Scala Jr., N. Greenhouse gas balance and carbon footprint of beef cattle in three contrasting pasture-management systems in Brazil. *J. Clean. Prod.* **2017**, *142*, 420–431. [CrossRef]
20. Filho, K.E. Supply chain approach to sustainable beef production from a Brazilian perspective. *Livest. Prod. Sci.* **2004**, *90*, 53–61. [CrossRef]
21. Flysjö, A.; Cederberg, C.; Henriksson, M.; Ledgard, S. The interaction between milk and beef production and emissions from land use change–Critical considerations in life cycle assessment and carbon footprint studies of milk. *J. Clean. Prod.* **2012**, *28*, 134–142. [CrossRef]
22. Ridoutt, B.G.; Page, G.; Opie, K.; Huang, J.; Bellotti, W. Carbon, water and land use footprints of beef cattle production systems in southern Australia. *J. Clean. Prod.* **2014**, *73*, 24–30. [CrossRef]
23. Fernandes, E.A.N.; Sarriés, G.A.; Bacchi, M.A.; Mazola, Y.T.; Gonzaga, C.L.; Sarriés, S.R.V. Trace elements and machine learning for Brazilian beef traceability. *Food Chem.* **2020**, *333*, 127462. [CrossRef]
24. Reis, J.C.; Rodrigues, G.S.; Barros, I.; Rodrigues, R.A.R.; Garrett, R.D.; Valentim, J.F.; Kamoi, M.Y.T.; Michetti, M.; Wruck, F.J.; Rodrigues-Filho, S.; et al. Integrated crop-livestock systems: A sustainable land-use alternative for food production in the Brazilian Cerrado and Amazon. *J. Clean. Prod.* **2021**, *283*, 124580. [CrossRef]
25. Röös, E.; Bajzelj, B.; Weil, C.; Andersson, E.; Bossio, D.; Gordon, L.J. Moving beyond organic–A food system approach to assessing sustainable and resilient farming. *Glob. Food Sec.* **2021**, *28*, 100487. [CrossRef]
26. Picanço Filho, A.F.; Figueiredo, R.S.; Oliveira Neto, O.J. Aplicação da metodologia system dynamics na avaliação da sustentabilidade econômico-financeira da bovinocultura de corte no município de Parintins–Estado do Amazonas. *Custos Agronegócio* **2009**, *5*, 33–58.

27. Arrieta, E.M.; Cabrol, D.A.; Cuchietti, A.; González, A.D. Biomass consumption and environmental footprints of beef cattle production in Argentina. *Agric. Syst.* **2020**, *185*, 102944. [CrossRef]
28. Souza, N.R.D.; Fracarolli, J.A.; Junqueira, T.L.; Chagas, M.F.; Cardoso, T.F.; Watanabe, M.D.B.; Cavalett, O.; Venzke Filho, S.P.; Dale, B.E.; Bonomi, A.; et al. Sugarcane ethanol and beef cattle integration in Brazil. *Biomass Bioenergy* **2019**, *120*, 448–457. [CrossRef]
29. Sobrosa Neto, R.C.; Berchin, I.I.; Magtoto, M.; Berchin, S.; Xavier, W.G.; Guerra, J.B.S.O.A. An integrative approach for the water-energy-food nexus in beef cattle production: A simulation of the proposed model to Brazil. *J. Clean. Prod.* **2018**, *204*, 1108–1123. [CrossRef]
30. Tongwane, M.I.; Moeletsi, M.E. Emission factors and carbon emissions of methane from enteric fermentation of cattle produced under different management systems in South Africa. *J. Clean. Prod.* **2020**, *265*, 121931. [CrossRef]
31. Freitas, D.S.; Oliveira, T.E.; Oliveira, J.M. Sustainability in the Brazilian pampa biome: A composite index to integrate beef production, social equity, and ecosystem conservation. *Ecol. Indic.* **2019**, *98*, 317–326. [CrossRef]
32. Santos, S.A.; Lima, H.P.; Massruhá, S.M.F.S.; Abreu, U.G.P.; Tomás, W.M.; Salis, S.M.; Cardoso, E.L.; Oliveira, M.D.; Soares, M.T.S.; Santos Jr, A.; et al. A fuzzy logic-based tool to assess beef cattle ranching sustainability in complex environmental systems. *J. Environ. Manag.* **2017**, *198*, 95–106. [CrossRef]
33. Costa Jr, N.B.; Baldissera, T.C.; Pinto, C.E.; Garagorry, F.C.; Moraes, A.; Carvalho, P.C.F. Public policies for low carbon emission agriculture foster beef cattle production in southern Brazil. *Land Use Policy* **2019**, *80*, 269–273. [CrossRef]
34. Costantini, M.; Vázquez-Rowe, I.; Manzardo, A.; Bacenetti, J. Environmental impact assessment of beef cattle production in semi-intensive systems in Paraguay. *Sustain. Prod. Consum.* **2020**, *27*, 269–281. [CrossRef]
35. Mazzetto, A.M.; Bishop, G.; Styles, D.; Arndt, C.; Brook, R.; Chadwick, D. Comparing the environmental efficiency of milk and beef production through life cycle assessment of interconnected cattle systems. *J. Clean. Prod.* **2020**, *277*, 124108. [CrossRef]
36. Oliveira, P.P.A.; Berndt, A.; Pedroso, A.F.; Alves, T.C.; Pezzopane, J.R.M.; Sakamoto, L.S.; Henrique, F.L.; Rodrigues, P.H.M. Greenhouse gas balance and carbon footprint of pasture-based beef cattle production systems in the tropical region (Atlantic Forest biome). *Animal* **2020**, *14*, 427–437. [CrossRef]
37. Knoll, S.; Padula, A.D.; dos Santosc, M.C.; Pumid, G.; Zhoue, S.; Zhonge, F.; Barcellosf, J.O.J. Information flow in the Sino-Brazilian beef trade. *Int. Food Agribus. Man.* **2018**, *21*, 17–37. [CrossRef]
38. Salvin, H.E.; Lees, A.M.; Cafe, L.M.; Colditz, I.G.; Lee, C. Welfare of beef cattle in Australian feedlots: A review of the risks and measures. *Anim. Prod. Sci.* **2020**, *60*, 1569–1590. [CrossRef]
39. Galuchi, T.P.D.; Rosalesa, F.P.; Batalhac, M.O. Management of socioenvironmental factors of reputational risk in the beef supply chain in the Brazilian Amazon region. *Int. Food Agribus. Man.* **2019**, *22*, 155–171. [CrossRef]
40. Wiśniewska-Paluszak, J.; Paluszak, G. Development of sustainable resource ties in the agri-food industry: The case for the Polish fruit and vegetable industry. *Int. Food Agribus. Man.* **2021**, *24*, 293–320.
41. Herring, A.D. Beef Cattle. In *Encyclopedia of Agriculture and Food Systems*; Van Alfen, N.K., Ed.; Academic Press: Oxford, UK, 2014; pp. 1–20. [CrossRef]
42. Sowell, B.F.; Mosley, J.C.; Bowman, J.G.P. Social behavior of grazing beef cattle: Implications for management. In *Proceedings of the American Society of Animal Science*; Montana State University: Bozeman, MT, USA, 1999.
43. Grignard, L.; Boissy, A.; Boivin, X.; Garel, J.P.; Le Neindre, P. The social environment influences the behavioural responses of beef cattle to handling. *Appl. Anim. Behav. Sci.* **2000**, *68*, 1–11. [CrossRef]
44. Sulfiar, A.E.T.; Guntoro, B.; Atmoko, B.A.; Budisatria, I.G.S. Sustainability of beef cattle farming production system in South Konawe Regency, Southeast Sulawesi. *J. Indones. Trop. Anim. Agric.* **2022**, *47*, 155–156. [CrossRef]
45. Martinez, C.C.; Maples, J.G.; Benavidez, J. Beef Cattle Markets and COVID-19. *Appl. Econ. Perspect. Policy* **2021**, *43*, 304–314. [CrossRef]
46. Souza, M.T.; Silva, M.D.; Carvalho, R. Integrative review: What is it? How to do it? *Einstein* **2010**, *8*, 102–106. [CrossRef]
47. Torraco, R.J. Writing Integrative Literature Reviews: Guidelines and Examples. *Hum. Resour. Dev. Rev.* **2005**, *4*, 356–367. [CrossRef]
48. Snyder, H. Literature review as a research methodology: An overview and guidelines. *J. Bus. Res.* **2019**, *104*, 333–339. [CrossRef]
49. Page, M.J.; McKenzie, J.E.; Patrick Bossuyt, P.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *J. Clin. Epidemiol.* **2021**, *134*, 178–189. [CrossRef] [PubMed]
50. Chifor, C.; Arion, I.D.; Isarie, V.I.; Arion, F.H. A Systematic Literature Review on European Food Quality Schemes in Romania. *Sustainability* **2022**, *14*, 16176. [CrossRef]
51. Tardioli, G.; Kerrigan, R.; Oates, M.; O'Donnell, J.; Finn, D.P. Identification of representative buildings and building groups in urban datasets using a novel pre-processing, classification, clustering and predictive modelling approach. *Build. Environ.* **2018**, *140*, 90–106. [CrossRef]
52. Ly, A.; Cornelisse, J. How to Train a Machine Learning Model in Jasp: Clustering. Available online: https://jasp-stats.org/2019/11/19/how-to-train-a-machine-learning-model-in-jasp-clustering/ (accessed on 16 July 2021).
53. Naghizadeh, A.; Metaxas, D.N. Condensed Silhouette: An optimized filtering process for cluster selection in k-means. *Procedia Comput. Sci.* **2020**, *176*, 205–214. [CrossRef]
54. Morissette, L.; Chartier, S. The k'means clustering technique: General considerations and implementation in Mathematica. *Tutor Quant Methods Psychol.* **2013**, *9*, 15–24. [CrossRef]

55. Gomes, E.G.; Abreu, U.G.P.; Mello, J.C.C.B.S.; Carvalho, T.B.; Zen, S. Unitary input DEA model to identify beef cattle production systems typologies. *Pesqui. Oper.* **2012**, *32*, 389–406. [CrossRef]
56. Cerri, C.C.; Moreira, C.S.; Alves, P.A.; Raucci, G.S.; Castigioni, B.A.; Mello, F.F.C.; Cerri, D.G.P.; Cerri, C.E.P. Assessing the carbon footprint of beef cattle in Brazil: A case study with 22 farms in the state of Mato Grosso. *J. Clean. Prod.* **2016**, *112*, 2593–2600. [CrossRef]
57. Florindo, T.J.; Florindo, G.I.B.M.; Talamini, E.; Costa, J.S.; Ruviaro, C.F. Carbon footprint and life cycle costing of beef cattle in the Brazilian midwest. *J. Clean. Prod.* **2017**, *147*, 119–129. [CrossRef]
58. Escribano, A.J.; Gaspar, P.; Mesías, F.J.; Pulido, A.F.; Escribano, M. Evaluación de la sostenibilidad de explotaciones de vacuno de carne ecológicas y convencionales en sistemas agroforestales: Estudio del caso de las dehesas. *Inf. Téc. Econ. Agrar.* **2014**, *110*, 343–367. [CrossRef]
59. Escribano, A.J. Beef cattle farms' conversion to the organic system. Recommendations for success in the face of future changes in a global context. *Sustainability* **2016**, *8*, 572. [CrossRef]
60. Sheppard, S.C.; Bittman, S.; Donohoe, G.; Flaten, D.; Wittenberg, K.M.; Small, J.A.; Berthiaume, R.; McAllister, T.A.; Beauchemin, K.A.; McKinnon, J.; et al. Beef cattle husbandry practices across Ecoregions of Canada in 2011. *Can. J. Anim. Sci.* **2015**, *95*, 305–321. [CrossRef]
61. Macitelli, F.; Braga, J.S.; Gellatly, D.; Costa, M.J.R.P. Reduced space in outdoor feedlot impacts beef cattle welfare. *Animal* **2020**, *14*, 2588–2597. [CrossRef]
62. Malan, J.-A.C.; Flint, N.; Jackson, E.L.; Irving, A.D.; Swain, D.L. Environmental factors influencing cattle's water consumption at offstream watering points in rangeland beef cattle. *Livest. Sci.* **2020**, *231*, 103868. [CrossRef]
63. Souza, H.A.; Moraes, E.H.B.K.; Oliveira, A.S.; Batista, E.D.; Santos, K.R.; Sousa, J.N.; Ortelan, J.C.; Lamag, A.; Moraes, K.A.K. Cashew processing product as alternative energy feedstuff for grazing beef cattle under tropical conditions. *Livest. Sci.* **2020**, *236*, 104022. [CrossRef]
64. Rivero, A.R.G.; Daim, T. Technology roadmap: Cattle farming sustainability in Germany. *J. Clean. Prod.* **2017**, *142*, 4310–4326. [CrossRef]
65. Sun, Y.; Yang, C.; Wang, M.; Xiong, X.; Long, X. Carbon Emission Measurement and Influencing Factors of China's Beef Cattle Industry from a Whole Industry Chain Perspective. *Sustainability* **2022**, *14*, 15554. [CrossRef]
66. Pacheco, J.W. Guia Técnico Ambiental de Frigoríficos: Industrialização de Carnes (Bovina e Suína). Available online: https://cetesb.sp.gov.br/consumosustentavel/wp-content/uploads/sites/20/2013/11/frigorifico.pdf (accessed on 8 March 2021).
67. Liang, C.; MacDonald, J.D.; Desjardins, R.L.; McConkey, B.G.; Beauchemin, K.A.; Flemming, C.; Cerkowniak, D.; Blondel, A. Beef cattle production impacts soil organic carbon storage. *Sci. Total Environ.* **2020**, *718*, 137273. [CrossRef]
68. Bilotto, F.; Vibart, R.; Wall, A.; Machado, C.F. Estimation of the inter-annual, arginal value of additional feed and its replacement cost for beef cattle systems in the Flooding Pampas of Argentina. *Agric. Syst.* **2021**, *187*, 103010. [CrossRef]
69. Soares, J.P.G.; Neves, D.L.; Carvalho, J.M. Produção de Carne Bovina em Sistema Orgânico: Desafios e Tecnologias Para um Mercado em Expansão. Available online: https://www.alice.cnptia.embrapa.br/alice/handle/doc/1002261?mode=full (accessed on 22 April 2021).
70. Flachowsky, G. Nutrition and feeding of organic cattle. *Anim. Feed Sci. Technol.* **2011**, *169*, 288–289. [CrossRef]
71. Rodríguez-Bermúdez, R.; Herrero-Latorre, C.; López-Alonso, M.; Losada, D.E.; Iglesias, R.; Miranda, M. Organic cattle pro-ducts: Authenticating production origin by analysis of serum mineral content. *Food Chem.* **2018**, *264*, 210–217. [CrossRef]
72. Balbino, L.C.; Barcellos, A.O.; Stone, L.F. *Marco Referencial: Integração Lavoura-Pecuária-Floresta*; Brazilian Agricultural Research Corporation, Embrapa: Brasília, Brazil, 2011.
73. *Carne Carbono Neutro: Um Novo Conceito Para Carne Sustentável Produzida Nos Trópicos*; Brazilian Agricultural Research Corporation, Embrapa: Brasília, Brazil, 2015. Available online: https://www.embrapa.br/en/busca-de-publicacoes/-/publicacao/1056155/carne-carbono-neutro-um-novo-conceito-para-carne-sustentavel-produzida-nos-tropicos (accessed on 23 April 2021).
74. Fiore, M.; Spada, A.; Contò, F.; Pellegrini, G. GHG and cattle farming: CO-assessing the emissions and economic performances in Italy. *J. Clean. Prod.* **2018**, *172*, 3704–3712. [CrossRef]
75. Gardini, A.O.; Matias, M.J.A.; Azevedo, D.B. Programas e práticas sustentáveis na bovinocultura de corte de Mato Grosso do Sul: Caminhos para a consolidação de uma bovinocultura sustentável. *Rev. Adm. Contab. Sustentabilidade* **2014**, *4*, 1–18. [CrossRef]
76. Chen, Z.; An, C.; Fang, H.; Zhang, Y.; Zhou, Z.; Zhou, Y.; Zhao, S. Assessment of regional greenhouse gas emission from beef cattle production: A case study of Saskatchewan in Canada. *J. Environ. Manag.* **2020**, *264*, 110443. [CrossRef] [PubMed]
77. Sabatier, P.; Weible, C. (Eds.) *Theories of the Policy Process*; Westview Press: Boulder, CO, USA, 2014.
78. Navarrete-Molina, C.; Meza-Herrera, C.A.; Herrera-Machuca, M.A.; Lopez-Villalobos, N.; Lopez-Santos, A.; Veliz-Deras, F.G. To beef or not to beef: Unveiling the economic environmental impact generated by the intensive beef cattle industry in an arid region. *J. Clean. Prod.* **2019**, *231*, 1027–1035. [CrossRef]
79. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [CrossRef]
80. Socio-Environmental Monitoring of the Cattle Sector in Brazil. Proforest Responsible Sourcing and Production Briefings, June 2017. Available online: https://www.proforest.net/resources/publications/socio-environmental-monitoring-of-the-cattle-sector-in-brazil-13547/ (accessed on 12 January 2023).
81. Porter, M. *On Competition*; Updated and Expanded Edition; A Harvard Business Review Book; Harvard Business Press: Harvard, MA, USA, 2008.

82. Amicarelli, V.; Fiore, M.; Bux, C. Hidden flows assessment in the agri-food sector: Evidence from Italian beef system. *Br. Food J.* **2021**, *123*, 384–403. [CrossRef]
83. Malafaia, G.C.; Mores, G.V.; Casagranda, Y.C.; Barcellos, J.O.J.; Costa, F.P. The Brazilian beef cattle supply chain in the next decades. *Livest. Sci.* **2021**, *253*, 104704. [CrossRef]
84. Groher, T.; Heitkämper, K.; Umstätter, C. Digital technology adoption in livestock production with a special focus on ruminant farming. *Animal* **2020**, *14*, 2404–2413. [CrossRef] [PubMed]
85. Connolly, A. February 2022 8 Digital Technologies for a New Era of Beef Production. Available online: https://www.agricultureportal.co.za/index.php/agri-index/69-animals/7473-8-digital-technologies-for-a-new-era-of-beef-production (accessed on 12 January 2023).
86. Helzer, C. *A Roadmap to a Sustainable Beef System. A Collaborative Approach to Achieve Economic and Environmental Benefits for People and Nature*; The Nature Conservancy: Arlington, TX, USA, 2020. Available online: https://www.nature.org/content/dam/tnc/nature/en/documents/TNCBeefRoadmap_FINAL_April152020.pdf (accessed on 12 January 2023).
87. NSW Government 2023, Department of Primary Industries, Responsible, Sustainable Beef Production. Available online: https://www.dpi.nsw.gov.au/animals-and-livestock/beef-cattle/husbandry/general-management/production (accessed on 17 February 2023).
88. Dick, M.; Silva, M.A.; Silva, R.R.F.; Ferreira, O.G.L.; Maia, M.S.; Lima, S.F.; Paiva Neto, V.B.; Dewes, H. Environmental impacts of Brazilian beef cattle production in the Amazon, Cerrado, Pampa, and Pantanal biomes. *J. Clean. Prod.* **2021**, *311*, 127750. [CrossRef]
89. Berndt, A.; Tomkins, N.W. Measurement and mitigation of methane emissions from beef cattle in tropical grazing systems: A perspective from Australia and Brazil. *Animal* **2013**, *7*, 363–372. [CrossRef]