Sustainability in the Beef Cattle Industry in Brazil

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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.

emerging markets and developing economies | sustainability | agri-food sectors

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. 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].

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][24][25][26]; decrease commercial emissions; and introduce new technologies for energy consumption, the usage of renewable energy in integrated systems, forage types [27][28][29][30][31], forest management and integration with other systems, greenhouse gas emissions, water and land usage [11][21][22][32][33][34][35][36] and pasture management [18][19].

2. Thematic Synthesis

(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 [37].

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 [38]. 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 [39]. 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][40][41][42]. 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 [43]. 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 [44]. 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 [43].

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][45]. 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][46].

(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 [37]. 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 [47]. However, there are few studies on the impacts caused by production and mitigation regarding beef cattle production [48]. A better understanding of technologies can be an alternative to using natural resources in production, thereby reducing the impacts caused [49].

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 [50]. It leads to a synergy between industries, design, and production management [51].

(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 [52]. 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 [53]. 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 [54].

(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) [55][56]. 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 [56]. However, the issue to be addressed is the relationship between production performance and emissions [57].

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 [58][59]. 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 [55][60].

3. 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 [61][62][63]. 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 [59]. 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 [64].

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 [65]. The beef cattle industry also undergoes wastage-related losses in natural resources (e.g., water and energy) and feed losses when storing and packaging [66]. 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 [67]. 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][68].

The complexity of the economic, environmental and social relationships in agri-food sectors, like beef cattle [69], 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 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 [59]. 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 [65].

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 [65]. 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.

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 [70]. 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 [71].

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 [39][43][45]. 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][38].

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][45]. 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 [39]. 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][39][43][45].

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 [72].

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 [73], 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 [73], 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 [72].

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 [74].

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.
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.
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.
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.
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.
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.
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.
12. Mirek, Z.; Witkowski, Z. Theory and practice in nature conservation–Where to seek sustainability? Pap. Glob. Chang. IGBP 2017, 24, 67–82.
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.
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.
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.
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.
20. Filho, K.E. Supply chain approach to sustainable beef production from a Brazilian perspective. Livest. Prod. Sci. 2004, 90, 53–61.
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.
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.
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.
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.
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.
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.
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.
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.
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.
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.
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.
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.
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.
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.
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.
37. 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.
38. 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.

39. 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.
40. 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.
41. 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.
42. 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.
43. 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.
44. 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.
45. 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.
46. Rivero, A.R.G.; Daim, T. Technology roadmap: Cattle farming sustainability in Germany. J. Clean. Prod. 2017, 142, 4310–4326.
47. 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.
48. 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).
49. 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.
50. 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.
51. 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).

52. Flachowsky, G. Nutrition and feeding of organic cattle. Anim. Feed Sci. Technol. 2011, 169, 288–289.
53. 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.
54. Balbino, L.C.; Barcellos, A.O.; Stone, L.F. Marco Referencial: Integração Lavoura-Pecuária-Floresta; Brazilian Agricultural Research Corporation, Embrapa: Brasília, Brazil, 2011.
55. 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).
56. 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.
57. 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.
58. 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.
59. Sabatier, P.; Weible, C. (Eds.) Theories of the Policy Process; Westview Press: Boulder, CO, USA, 2014.
60. 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.
61. Torraco, R.J. Writing Integrative Literature Reviews: Guidelines and Examples. Hum. Resour. Dev. Rev. 2005, 4, 356–367.
62. Snyder, H. Literature review as a research methodology: An overview and guidelines. J. Bus. Res. 2019, 104, 333–339.
63. Braun, V.; Clarke, V. Using thematic analysis in psychology. Qual. Res. Psychol. 2006, 3, 77–101.
64. 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).

65. Porter, M. On Competition; Updated and Expanded Edition; A Harvard Business Review Book; Harvard Business Press: Harvard, MA, USA, 2008.
66. 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.
67. 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.
68. 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.
69. 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.
70. Groher, T.; Heitkämper, K.; Umstätter, C. Digital technology adoption in livestock production with a special focus on ruminant farming. Animal 2020, 14, 2404–2413.
71. 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).
72. 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).
73. Martinez, C.C.; Maples, J.G.; Benavidez, J. Beef Cattle Markets and COVID-19. Appl. Econ. Perspect. Policy 2021, 43, 304–314.
74. 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).