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Towards a comprehensive sustainable assessment of beef cattle systems: integrating bioeconomics and animal science

Joana Gasparotto Kuhn[1*], Diego Durante Mühl[2], Cainã Lima Costa[3], Gabriela Alegretti[4], Letícia de Oliveira[2] and Edson Talamini[2]

[1]Programa de Pós-graduação em Zootecnia, Universidade Federal do Rio Grande do Sul, Av. Paulo Gama, 110, 90010-150, Porto Alegre, Rio Grande do Sul, Brasil. [2]Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brasil. [3]Programa de Pós-graduação em Agronegócios, Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brasil. [4]Instituto Brasileiro de Bioeconomia, Sapucaia do Sul, Rio Grande do Sul, Brasil. *Author for correspondence. E-mail: joanagk@hotmail.com

ABSTRACT. Studies with bioeconomic modeling can be identified in animal science. However, there are distinct typologies associated with the term bioeconomy with different meanings and approaches. The present study aims to examine the Bioeconomy/Bioeconomics approaches used in animal science research and discuss the implications and benefits of integrating these areas of knowledge. The method consisted of systematic literature review with quantitative and qualitative analyzes of the content of articles obtained from the Scopus® database. In the process of searching and analyzing the articles, we defined beef cattle as representative of animal science. Followed the PRISMA Protocol guidelines. The results confirmed that the use of the term bioeconomic has been recurrent in this field of knowledge since 1994. However, the approach given to the term refers mainly to studies combining animal performance (bio) and economic returns (economic) because of variables of interest, evident in the set of indicators reported in the articles analyzed. Despite the relevance of these studies, we discuss some implications and reasons for adopting other bioeconomy approaches in animal science. We conclude that the integration between Bioeconomics and animal science can significantly broaden the scope of analysis, the what relevant to the contemporary challenges of promoting sustainable production systems.

Keywords: bioeconomy; bioeconomic; livestock; sustainability; thermodynamics.

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Introduction

For over ten thousand years people have domesticated and managed ruminants for their ability to convert noncompetitive feed into food and other useful products for man (Mazoyer & Roudart, 2009). The complex interaction of ruminants with the ecosystem is a challenge to the sciences, especially when considering the global extent of the cattle herd, which in Brazil alone has more than 202 million head, making the country the largest exporter of beef in the world (*Associação Brasileira das Indústrias Exportadoras de Carnes* [ABIEC], 2023).

Knowledge areas such as animal science are continuously seeking to domesticate and manage these animals, but with a special focus on improving the use of resources. Their interest also lies in meeting the society demand for meat-based foods, which although the impact of the pandemic has not yet been fully mapped, it is estimated that about one-tenth of the global population—up to 811 million people—faced hunger by 2020 (Food and Agriculture Organization [FAO], 2020). The figure suggests that it will take a tremendous effort for the world to honor its promise to end hunger by 2030 (Food and Agriculture Organization [FAO], 2021).

However, overcoming these challenges requires interdisciplinary approaches. Still in the 20th century, the term ‘bioeconomy’ was used to designate and interconnect the fields of mathematical, natural, and social sciences with the knowledge of Biology and Economics (Bonaiuti, 2011). Presumably, the noun bioeconomy was introduced by Reinheimer (1913) and its definition was related to the study of how different organisms integrate into the ‘economy of nature’, highlighting the existing division of labor.

Later, the economic system began to be analyzed from the implications of the laws of thermodynamics inherent in the process of production and consumption. This analytical approach led to the emergence of a new field of knowledge in economics: ‘bioeconomics’. Bioeconomics is based on the seminal work of Georgescu-Roegen (1970) considering the entropic basis associated with the economic system. Contrary to the classical and neoclassical theories of economics, Georgescu-Roegen's view of bioeconomics inserted into the analysis of the economic process two previously ignored factors: resource scarcity and social institutions (Gowdy & Mesner, 1998; Mayumi, 2009). A more detailed description of Georgescu-Roegen's work and the dissensions it generated is presented in Gowdy and Mesner (1998) when they refer to the biological origin of the economic process.

The main consequence of subjecting the economic process to the laws of thermodynamics is that continuous growth is severely tested. The accumulation of capital is constrained by biophysical limits, and all work required involves energy transformation which implies some loss of energy through heat dissipation (Georgescu-Roegen, 1970; 2012). Although some of this energy can be recovered for some useful purpose, not all the heat generated can be used, so Georgescu-Roegen argued that the use of thermodynamics would be more pertinent to economics than mechanics, since, from the latter's perspective, economics could not affect the environment (Georgescu-Roegen, 1960; 2013).

Georgescu-Roegen's ideas have unfolded with advances in the analysis of the economic activities in the light of thermodynamics, especially after the Odum's (1996) work. On the other hand, growing concerns about the intensive use of limited and non-renewable resources, the demand for more sustainable processes and products, and the development of technological solutions to these problems have pushed the use of the term 'bioeconomy' to designate other specific domain fields.

In response, the term 'bioeconomy' has been associated with distinct typologies, depending on the context and interests involved. Vivien, Nieddu, Befort, Debref, and Giampietro (2019) argued that the term 'bioeconomy' has been hijacked from its original context and applied to distinct contemporary situations. As a fallout, the literature has identified at least three distinct typologies of 'bioeconomy': Type I - biosphere-compatible ecological economy; Type II - knowledge-based economy, in particular from industrial biotechnology; and, Type III - biomass-based economy (Bugge, Hansen, & Klitkou, 2016; Vivien et al., 2019, Befort, 2020; Mougenot & Doussoulin, 2021).

Therefore, currently we are faced with at least two distinct applications of the term 'bioeconomy': the noun bioeconomy, which defines the scope of the bio-based economy, and the bioeconomics, which defines the domains of a specific knowledge field. Terminological confusion may be relevant in languages where there is an absence of adequate terms to make this distinction, as in Portuguese, for example, where both the noun and the field of knowledge are defined by the term '*bioeconomia*'. An overview of the meaning, use and applications of 'bioeconomy' and 'bioeconomics' is provided by Zawojska and Siudek (2016), Birner (2018) and Tilica (2021). Although the term 'bioeconomy' refers to similar contexts, the specific analyses and applications related to bioeconomy and Bioeconomics are generally very different. In this sense, Mohammadian (2003, p. 320) defines 'bioeconomics' as a branch of economics that investigates "[...] the socioeconomic system in conjunction with the biological system as a whole [...]" and studies "[...] the non-linear interactions between its components".

By breaking the disciplinary boundaries for food production, bringing together areas of knowledge such as Bioeconomics and animal science, the possibilities for the analysis of production systems are broadened, especially considering their interactions with the biophysical environment. Given this, the questions to be answered are: have bioeconomy/Bioeconomics approaches been used by animal science in the analysis of production systems? If so, which bioeconomy approaches has been predominant in animal science studies? Are there gaps to be filled with potential gains for comprehensive knowledge production?

The present study aims to examine the Bioeconomy/Bioeconomics approaches used in animal science research, contrasting them with the typologies of bioeconomy pointed out in the literature and based on the findings to discuss the implications and benefits of integrating these areas of knowledge. For the present analysis, we have chosen to restrict the scope to research involving beef cattle due to its relative importance in the animal sciences. The assumption is that the bioeconomy/Bioeconomics approaches present similar applications among the specific domains of animal science.

Materials and method

The used method is a literature review based on qualitative analysis. The systematic literature review (SLR) was performed based on the requirements of the PRISMA Statement-Preferred Reporting Items for Systematic reviews and Meta-Analyses (Moher, Liberati, Tetzlaff, Altman, & PRISMA Group, 2009) with the purpose of accumulating existing information in the literature in a planned manner. By applying this method, it is possible to map the state of the art of a topic. The PRISMA protocol consists of three steps: selection, exclusion, and eligibility, which will be detailed throughout this section.

Step 1: selection

The article portfolio was retrieved from the Scopus® because it is a database that offers a broad view of the global and interdisciplinary scientific literature (Retrieved from https://www.elsevier.com/products/scopus/content). The purpose of the research was to identify the bioeconomy/Bioeconomics approach used in the scientific domain of animal science, particularly in studies related to beef cattle. To collect documents (articles), the terms 'bovine' OR 'beef cattle' AND 'bioeconomic' OR 'bioeconomy' were entered into the 'Search documents' field of the Scopus search engine and between the 'Search within' options was selected: 'Article title, Abstract, Keywords'. All articles retrieved between the years 1994 (first occurrence) to 2021 were considered, and the filter for 'full articles' was applied. The search and collection of articles was performed on January 7, 2021 and updated on July 26, 2021. The update was necessary to include in the analysis the last articles published in the year 2020.

Step 2: exclusion

Information such as article title, source title, authors' name, and year of publication of the articles selected for the systematic review were extracted and organized in a spreadsheet (Microsoft Excel®). First, duplicate articles were excluded using the Microsoft Excel data menu and the remove duplicate cells option. Besides the help of the function, we manually verified the repetition of titles, authors, and files with the same content but in different languages.

After finishing the step of excluding identical articles, four additional exclusion criteria were defined and applied: 1st) Articles full-text access needed to be granted by UFRGS - Universidade Federal do Rio Grande do Sul or '*Periódicos Capes*' - *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior*; 2nd) Does the article clearly mention biological variables (zootechnical, agronomic or environmental indices) and as stabilizing or bioeconomic variables (economic, financial, flow or social indices)? This criterion had the function of excluding articles that did not emphasize these elements of bioeconomy; 3rd) Does the article contain descriptions of bioeconomy/Bioeconomics contextualized to beef production? This criterion had the objective of identifying applications linked to the productive and commercial operations of agents in supply chain such as: nutrition, reproduction, production, etc. through the reading of the abstracts; and 4th) The documents had to be scientific articles composed of standard textual elements (introduction, objectives, theoretical framework, methodology, results, and conclusions).

Step 3: eligibility

The remaining articles after the exclusion criteria went through a qualitative screening process aiming to ensure the eligibility or adequacy as the objective of the study. To do so, the selected articles were submitted to a content analysis with the purpose of confirming whether the selected documents expressed results consistent with the use of 'Bioeconomics' or 'Bioeconomy' approaches in research related to beef cattle. For the screening of the articles, the strategy of dismemberment of the main objective was used, observing, in a first moment, which research problem in bioeconomics was being addressed in the article. Then, it is verified if the issue of natural resources and biotechnological innovations in any of the activities related to beef cattle raising is being addressed. A total of 397 articles were found (Figure 1), by limiting the open access works, there are 91 articles in the database. Eighteen publications were excluded by reading the title and 33 by reading the abstract.

During the eligibility step, articles that dealt with dairy cattle were eliminated (27.5%). One article was excluded (1.7%) for using the word bioeconomy only in the abstract without addressing the subject throughout the text. Among the excluded articles, 46.5% did not refer to bovine management and/or production, but to the use of bovine by-products, such as bovine blood for poultry nutrition. Two articles (3.44%) were excluded because they referred to broilers and fish, and 6.8% of the articles were excluded because they studied dairy sheep. At the end of this process, 33 articles were selected and analyzed.

About selected articles and content analysis

From the thirty-three selected articles, 15.1% were published before the 2000s. From 2005 to 2010 the same relative part of the sample (15.1%) was observed. From 2011 to 2015 this figure more than doubled, reaching 36.3% of publications with the remaining 33.3% having been published between 2016 to 2020.

The profile of the selected articles shows that publications on the topic have been concentrated in a few journals. Overall, articles published in 17 journals were collected (Figure 3). The *Revista Brasileira de Zootecnia* is the journal with the highest frequency of publications, accounting for 24.2% of the retrieved articles, followed by the Journal of Animal Science with 12.1% and the journal *Arquivos de Zootecnia* in which 9% of the selected articles were published.

Microsoft Excel ®, v. 16, was used for data analysis. The VosViewer® software was used to measure and illustrate the keywords co-occurrence analysis according to Zipf's Laws for bibliometrics (word frequencies) (Guedes & Borschiver, 2005; Newman, 2005).

Results and discussion

Analyzing the content of the selected articles, we sought to find the occurrence of words according to Zipf's law, identifying a small number of words that occurred many times or many words with low frequency (Figure 2). Using the co-occurrence of keywords feature of the VosViewer® software, it was possible to visualize the relationship between the 15 main keywords with higher occurrence (Figure 4).

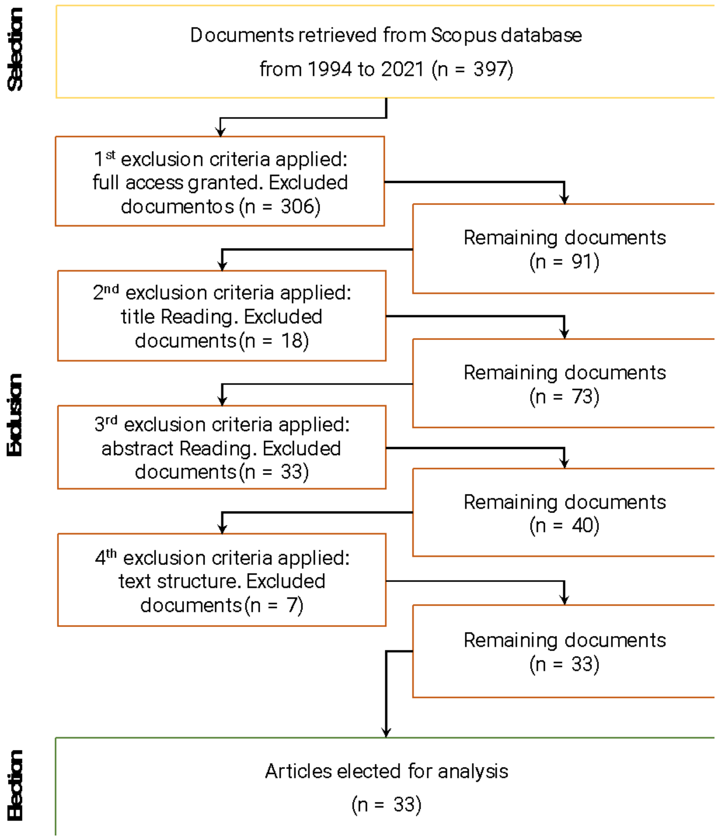

Figure 1. Diagram with systematic review steps and the number of documents retrieved, excluded, and selected for the analysis. Adapted from the PRISMA guidelines (Moher et al., 2009).

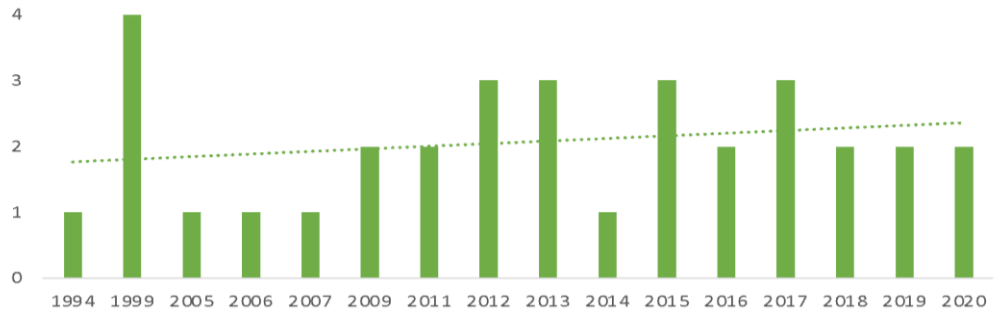

Figure 2. Frequency of articles selected for analysis, articles/year (n = 33 articles). Source: research data.

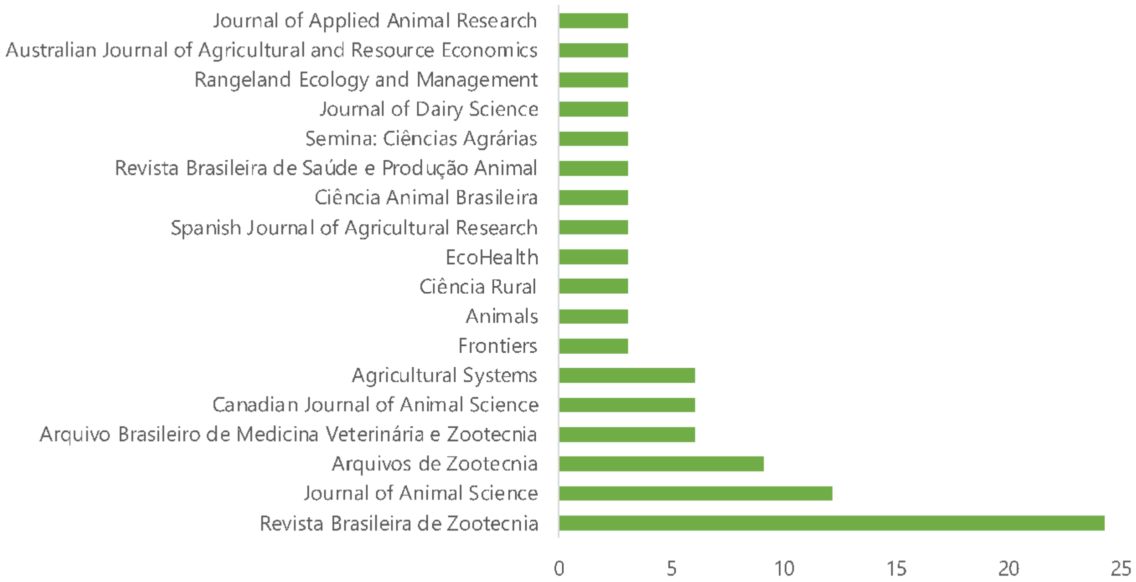

Figure 3. Frequency of selected articles published by periodicals, %. Source: research data.

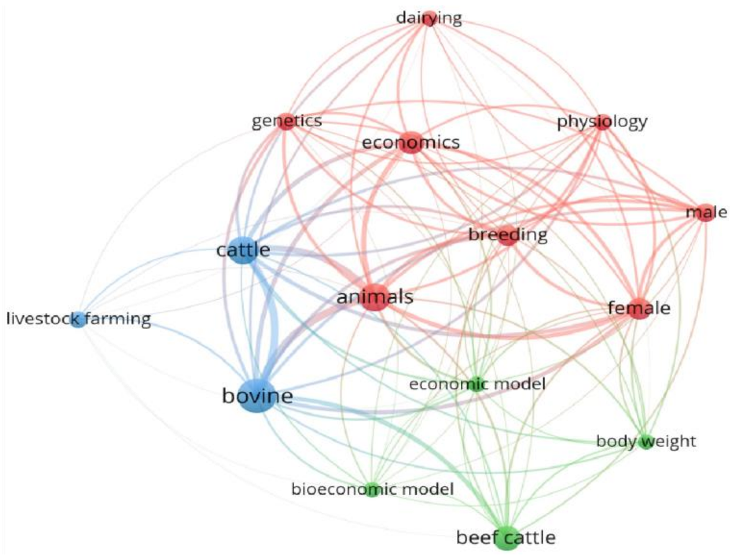

Figure 4. Co-occurrence of the fifteen most frequent keywords identified in the selected articles. Source: research data.

VosViewer uses statistical features, keyword counting, word co-occurrence analysis, and citation analysis to create concept networks based on the VOS - visualization of similarity - algorithm. The software creates a map where the distance of objects (words) is established according to the mathematical similarity between the terms (Van Eck & Waltman, 2019).

Figure 4 shows three clusters of keywords with the highest co-occurrence. The first refers to beef cattle production systems and is defined by the terms: ‘bovine’, ‘cattle’, and ‘livestock farming’. The second brings together economic aspects with animal characteristics and is defined by the terms: ‘animals’, ‘economics’, ‘breeding’, ‘male’, ‘female’, ‘genetics’, ‘physiology’, and ‘dairying’. The third cluster is the one associated with the approach of bioeconomy employed in the selected studies, defined by the terms: ‘beef cattle’, ‘bioeconomic model’, ‘economic model’, and ‘body weight’.

Judging by the frequency of the term ‘bioeconomic’ and its co-occurrence with the other keywords, little emphasis has been given to bioeconomy (Type I) in such studies. That is, the bioeconomic approach seems to make only a marginal contribution in beef cattle zootechnical studies. Furthermore, it is evident that bioeconomic models have been used to combine the analysis of the zootechnical performance of animals (‘body weight’) because of animals’ characteristics such as sex (‘male’, ‘female’), genetics (‘genetics’) or breed (‘breeding’), with the purely economic counterpart (‘economics’, ‘economic model’, ‘bioeconomic model’), mainly economic viability.

This evidence is corroborated by the indicators used in the studies.-The indicators were identified and classified according to ‘economic’, ‘productive’ or ‘environmental’ scope where they were applied (Figure 5).

It was found that 60% of the indicators used are aimed at measuring productive aspects, while 39.3% of them are aimed at measuring economic aspects and only 0.69% evaluate environmental aspects.

The number of indicators per study varied significantly. Marques et al. (2017) used the largest number of indicators (n = 47), followed by López-Paredes, Jiménez-Montero, Pérez-Cabal, González-Recio, and Alenda (2017) and Santana Barbosa, Mandarino, and Lobo (2013). The average was 15 indicators used in each of the selected articles.

Deepening the analysis, we found a list of productive, economic, environmental, and mixed indicators (Figure 6).

Forty-eight indicators were identified, of which 16 (33.3%) were classified as economic indicators, 27 (56.3%) as productive indicators, 4 (8.3%) as environmental indicators, and 1 (2.1%) classified as mixed. Costs and expenses, price, revenues, profit, and productivity are among the most frequently used economic indicators. Among the indicators associated with productive aspects, the most frequent were number of animals, weight, diseases, daily weight gain, carcass characteristics, animal diet characteristics, mortality, genetic characteristics, and birth rate. Although low frequency, four environmental indicators were identified, all of them associated with soil carbon or emissions. The types of indicators and their frequency reinforce the evidence that bioeconomy studies applied to beef cattle ranching seek to qualify the joint analysis of biological/zootechnical and economic variables.

Both by the co-occurrence of keywords, and the type of indicators used in studies involving bioeconomy in beef cattle, the results show evidence of particular bias in animal science. This particularity denotes a relatively restricted scope of bioeconomic analysis. In the next section, we discuss the implications of our findings and argue about the benefits of broadening the scope to the Bioeconomy and the potential benefits for beef cattle, in particular, and animal science, in general.

Bioeconomy/bioeconomics approaches

The term bioeconomy identified in the selected articles does not adhere to the typologies of bioeconomy reported in the literature (Bugge et al., 2016; Vivien et al., 2019, Befort, 2020; Mougenot & Doussoulin, 2021). In general, they present analyses based on economic aspects, where bioeconomy means economic efficiency related to purchase and sales prices, costs, revenues, and financial returns, resulting from husbandry performance and measured by indicators of production-economic efficiency. Such efficiency is addressed under the designation of bioeconomic or bioeconomical efficiency connecting the animal performance (bio) with economic variables since they seek to define or develop production and consumption models, Commonly, such studies explore the best relationship between product, time, and resources.

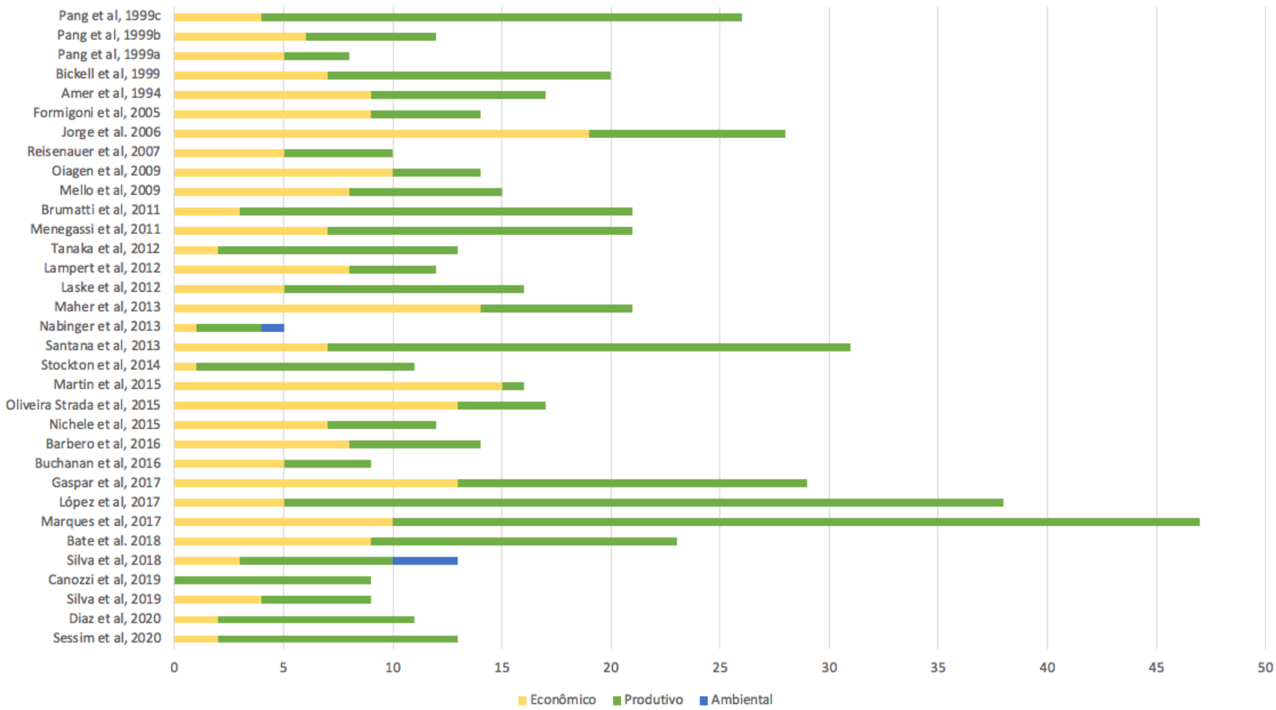

Figure 5. Classification of indicators according to scope and their frequency in the selected articles. Source: research data.

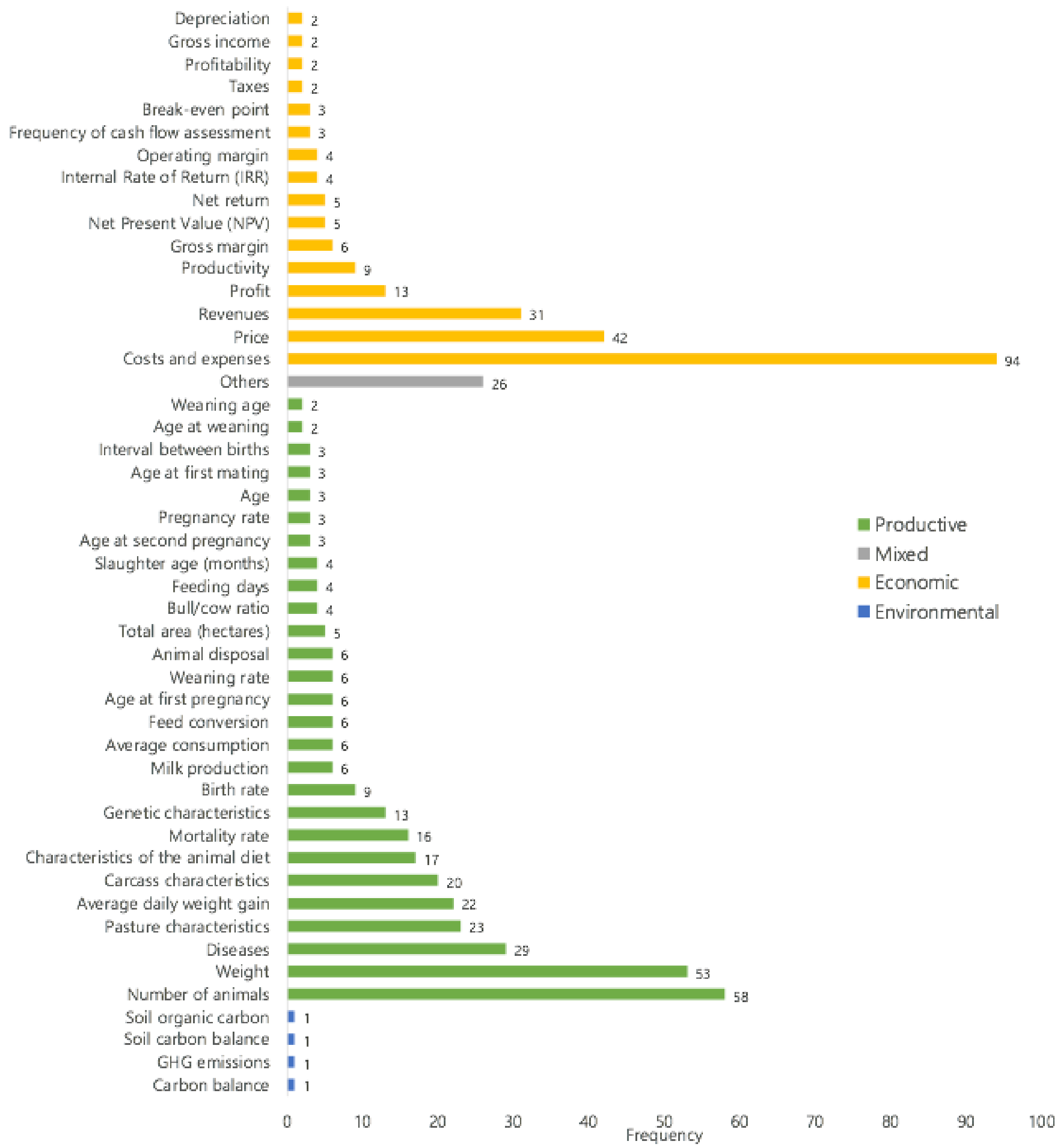

Figure 6. Indicators used in the selected articles, frequency and category. Source: research data.

Among the retrieved articles, Oiagen et al. (2008), for example, used the term 'bioeconomic performance of breeding herds' to denote the positive correlations of pregnancy percentage and weaning rate with profitability and negative correlations of the annual cost of cows with the profitability of production systems. The article by Nichele et al. (2015) reports that bioeconomic efficiency is a discrimination index used to define in which aspect one group of animals is more efficient than the other.

Other results with economic analyses have been named with the term bioeconomic, such as the more recent articles by Marques et al. (2017); Silva et al. (2019) and Sessim, Oliveira, López-González, Freitas, and Barcellos (2020). Following the approach of using only economic and production data under the term bioeconomic Canozzi et al. (2019, p. 2) investigated the typology of rural producers to evaluate "[...] the bioeconomic efficiency of beef production systems in the State of Rio Grande do Sul, Brazil [...]" as the pattern of economic analyses, in opposition of the work of Dumont et al. (2020) which analyzed the multi-performance economic, productive, and environmental. Tanure, Nabinger, and Becker (2013, p. 3) created a model to support the decision-making process in agricultural production systems considering "[...] interrelated economic and biological components [...]" to address how to generate strategies that include economic outcomes, environmental impact assessment, and operational risk analysis.

The bioeconomy approach from the perspective of Type II and III (Vivien et al., 2019) appeared in only two studies, although used to analyze only marginal aspects associated with beef cattle production systems. Díaz et al. (2020) and Ferreira et al. (2018) analyzed the use of agroindustry residues and the use of biotechnologies in microalgae biomass, respectively, both for beef cattle nutrition. However, these authors did not spell out the theoretical arguments nor cite the Georgescu-Roegen's work or refers to the bioeconomy described by him. The use of the term bioeconomic was limited to the scope of producing economic-productive analyses based on animal performance.

The occurrence of the terms 'bioeconomy', 'bioeconomic', 'bioeconomics' or 'bioeconomic' among the keywords of the retrieved articles showed low frequency, even though it was included as a search indexer. That is, the term bioeconomy was relevant enough to appear among the 15 keywords (Van Eck & Waltman, 2019). This is an indication that, in addition to the fact that there are few studies addressing the theme bioeconomy in the field of animal science, the term bioeconomy has low relative weight. In recent years, the use of other terms has been observed, such as bionutritional efficiency, employed to define levels of live weight gain in response to dry matter intake (Pazdiora et al., 2013).

The language factor can interfere in this process. In the Portuguese language the word '*bioeconomia*' has a unique spelling, composed of the Greek radical 'bios', found in many hybrid words such as biology, being understood as 'study of life', combined with the base '*economia*'. However, the base '*economia*' can take on polysemic neologisms, even if we have an established conceptual understanding of these words. In the English language, the semantics of words that refer to the topic, such as 'economic' or 'economical' (adjectives), 'economics' (scientific domain) and 'economy' (noun) imply distinct discussions and applicability.

On the other hand, if the use of the term 'bioeconomic' was more frequent, the indicators used are based on analyses of models based on the economic diagram that represents a closed and circular production-consumption system. This approach restricts the analysis of production systems to their closed/internal context instead of an open subsystem integrated into a larger system, as proposed by Georgescu-Roegen (1975). Possibly, the foundation in the laws of thermodynamics to explain the economic activities like the beef cattle productive systems, may be a limiting factor due to the analytical complexity. However, the number of studies using this approach in animal systems has grown over the last decade (Wang et al., 2016; Rice, O'brien, Shalloo, & Holden, 2017; Allegretti, Talamini, Schmidt, Bogorni, & Ortega, 2018; Reis et al., 2021; Muñoz-Ulecia, Bernués, Briones-Hidrovo, Casasús, & Martín-Collado, 2023a; Muñoz-Ulecia et al., 2023b). Georgescu-Roegen considered several aspects of thermodynamics, such as entropy, irreversibility of processes, qualitative changes, true scarcity, and undeterminability, for understanding and explaining the economic system (Gowdy & Mesner, 1998), through increasing the complexity of the evaluation.

Why bring 'bioeconomics' closer together animal science?

Economists use fundamental concepts of neoclassical economics in the rationality of ecosystem management, whose logic is specific (Georgescu-Roegen, 1995). Thus, methodological options of thermodynamic analysis are used among which are energy analysis (EA), exergetic analysis (ExA), entropy analysis (EnA) and emergy analysis (EmA) (Liao et al., 2012). On the other hand, the selected studies on beef cattle show a more restricted approach, limited to bioeconomics focused on the relationship between animal performance (bio) and economic outcomes (economics).

Associating bioeconomics and animal science allows to give views to other topics than resources optimization, since 'Bioeconomics' cannot be studied without understanding the energy flows that drive the economy. Thus, the studies in animal science could be complemented by analyzing the impacts on thermodynamic indicators arising from zootechnical variables, such as genetic improvements, for example. To this end, the research questions could be adapted. For example, questions such as: What is the optimal pasture management structure, since under-grazing or over-grazing has less animal productivity than management with optimal heights? (Savian et al., 2018), could be rewritten for a 'Bioeconomics' analysis as follows: What are the levels of renewability of kg live weight produced in systems under different pasture management? Or what are the levels of (un)sustainability of beef production produced under different grazing management systems?

Bioeconomics' approach implies admitting other relevant particularities for the analysis of energy flows. Dick et al., (2021) points out that geographic and climatic characteristics impact energy use differently. For example, in the Midwest Region of Brazil more hectares are needed to produce the same number of grazing animals than other regions, due to greater dependence on rainfall. On the other hand, the availability of land in the Midwest Region allows the large-scale production of other agricultural crops such as soybeans and corn, allowing supplemental animal feed at lower costs and reducing dependence on pasture.

Beef cattle ranching can be considered an open thermodynamic system that exchanges energy and matter with its environment. For its maintenance over time, the system incorporates low entropy resources (matter and energy) that are transformed into high entropy (pollution, waste, heat). Therefore, the entropy generated by a system, including beef cattle systems, is a relevant indicator to analyze its (un)sustainability through the bioeconomics approach. In this perspective, the goal of a beef cattle production system can be stated as the search for the best relationship between low entropy resource use and the production of items to satisfy human needs. In other words, systems that generate fewer entropy units per unit of output since the performance of any work implies some entropy generation.

The second law of thermodynamics states that in any process, not all the available energy (exergy) is transformed into work, resulting in the generation of entropy. Following this law, it is possible to infer that not all the available energy contained in the inputs used for beef cattle production, such as feed or fertilizers, whether they come from nature or the economy, renewable or non-renewable, can be converted into products. As proposed by Artuzo, Allegretti, Santos, Silva, and Talamini (2021), at the end of the production cycle part of the energy is embedded in products, and the other remains within the system as stock (exergy). In the same way, because of the production cycle, unavoidably, another part of the energy (heat) is dissipated into the environment as entropy. When the use of non-renewable energy increases and the stored energy in systems decreases, the result is a less sustainable system. No matter how efficient the system is, it will still exhibit a certain level of unsustainability.

Some indicators or indices are well established and recurrent in bioeconomics' studies. Among the indicators that could be used to evaluate energy balances in animal production systems, there is, for example, the emergy yield ratio (EYR), which is a measure of the energy incorporation from nature and suggests the amount of energy from nature that the production process returns to the economic sector (Odum, 1996). Another indicator is the Total Emergy (Y) given by the total emergy flow or total emergy of a product or process resulting from the sum of the flows of emergy from nature (I) and the economy (F), measured in Joule of equivalent solar energy (seJ) (Odum, 1996). The higher the emergy flow of a product or process means a higher number of steps involved and consequently more emergy incorporated into the process. Indicators such as these are particularly interesting for the study of biobased production systems because they integrate biophysical variables into the analysis and allow approximations with the thermodynamic sustainability of these systems (Rótolo, Rydberg, Lieblein, & Francis, 2007; Almeida et al., 2010; Wu, Wu, Tong, & Jiang, 2013; Artuzo et al., 2021).

By using an interdisciplinary approach to promote practices and processes that increase primary resource efficiency, we are moving towards the bioeconomy as proposed by the Organization for Economic Cooperation and Development (OECD). The OECD concept of bioeconomy encompasses the principles regarding sustainable development based on resources, such as renewable biomass, knowledge, such as from biotechnology, and integrated applications (Organization for Economic Cooperation and Development [OECD], 2009). Therefore, the possibilities and needs for integration between animal science and the bioeconomy are visible, contributing directly to the knowledge construction and transference to beef cattle farmers other aspects beyond the maximization of monetary returns.

Contrary to Paarlberg (2009, p. 5) assertion, farmers care about environmental impacts and seek to preserve resources, often proceeding in an empirical manner based on direct observation of nature. Moreover, this concern is expressed in the relative importance given to private programs, consultancies and/or advisories, based on incentives for efficient management in rural areas. Extending the presence of bioeconomics bases in animal science with the use of (bio)technologies and the employment of various methods and metrics to measure interactions between resources, energy, production, and waste can result in more comprehensive knowledge about optimal management aligned with a contemporary perspective of integration between production systems and the biophysical environment.

In fact, studies of this nature have been published, but more can be done. Florindo, Florindo, Talamini, and Ruviaro (2017), for example, when studying the environmental life cycle from the perspective of 'bioeconomics', concluded that the slaughter of cattle at 20 months of age and 510 kg live weight, obtained the lowest greenhouse gas emissions per kilogram of live weight, 15.5 kg CO_2-eq. Other studies have focused on feed and feedlot manure utilization. Bouwman et al. (2013) estimated that the total nutrients of cattle manure, including non-herbivore species, exceed the nutrients of synthetic fertilizers globally, and its energy efficiency improved from 30 to 250% as a substrate for bioenergy by co-digestion (Duarte, Fragoso, Smozinski, & Tavares, 2021). Globally, livestock manure provides only about 12% of gross nitrogen input to agricultural crops and up to 23% in mixed crop-livestock systems in developing countries (Liu et al., 2010). Benez (2002) approaches bioeconomics empirically by studying the use of homeopathy and phytotherapy for the treatment of diseases in beef cattle farming.

Other studies in animal science have been dedicated to identifying strategies that minimize the use of the planet's energy resources in beef cattle production. Examples include studies of land use management and ecosystem services (Macintosh et al., 2019), ecosystem effects of crop-livestock integration (Smith et al., 2019), effect of grazing management by supply on the natural environment (Carvalho, Santos, & Neves, 2007; Boldrini, Overbeck, & Trevisan, 2015), grazing management, animal nutrition and multifunctional attributes of the environment (Carvalho et al., 2007), grazing management by rotational grazing system (Savian et al., 2018), management of production systems and carbon sequestration (Souza Filho et al., 2019). Despite the relevance of studies like these for animal science in general and for beef cattle in particular, the approach with bioeconomy could generate results for even broader analysis of production systems.

These studies show that there are already many strategies aimed at minimizing the use of natural resources in beef cattle production. However, they are not assessed and presented in the light of Georgescu-Roegen's 'bioeconomics'. Most researchers, when they do so, do it in a subliminal way, without resorting to bioeconomics indicators such as energy flows or balances and entropy generation. In the last years, the bioeconomy has broadened with the innovations linked to biological products and processes. Thus, in the emergy analysis of beef cattle farming, the more renewable natural resources used, the more sustainable become the production system in relation to the total emergy (Y), or even, the more non-renewable resources, the worse the EUI (Artuzo et al., 2021).

There is still a need to move beyond the bioeconomics critique of bioeconomy, adopting a systemic view and renewing the indicators (Allain, Ruault, Moraine, & Madelrieux, 2022). Finally, the reconfiguration of farming systems to reduce dependence on external resources and increase the availability and use of on-farm resources requires rethinking technological and organizational aspects, which in short, is seen in the presence of bioeconomy in beef cattle production.

Conclusion

The term bioeconomic when used in animal science refers to analyses that evaluate the zootechnical performance of animals (bio) and the financial returns (economics) together. Naturally, there is no objection to the use of the term in this sense. However, approximation with other 'bioeconomies' can broaden the scope, incorporating metrics energy accounting.

Too, there is a semantic and language interference in this field in the Portuguese language: 'Bioeconomy' (noun), for the bio-based supply and demand system (biomass and biotechnology); 'Bioeconomic' (adjective), to qualify bio-based economic system; and 'Bioeconomics' (noun), for scientific analysis of the economic system laws for thermodynamics.

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References

Allain, S., Ruault, J.-F., Moraine, M., & Madelrieux, S. (2022). The 'bioeconomics vs bioeconomy' debate: Beyond criticism, advancing research fronts. *Environmental Innovation and Societal Transitions, 42*, 58-73. DOI: https://doi.org/10.1016/j.eist.2021.11.004

Allegretti, G., Talamini, E., Schmidt, V., Bogorni, P. C., & Ortega, E. (2018). Insect as feed: an emergy assessment of insect meal as a sustainable protein source for the Brazilian poultry industry. *Journal of Cleaner Production, 171*, 403-412. DOI: https://doi.org/10.1016/j.jclepro.2017.09.244

Artuzo, F. D., Allegretti, G., Santos, O. I. B., Silva, L. X., & Talamini, E. (2021). Emergy unsustainability index for agricultural systems assessment: a proposal based on the laws of thermodynamics. *Science of the Total Environment, 759*, 143524. DOI: https://doi.org/10.1016/j.scitotenv.2020.143524

Associação Brasileira das Indústrias Exportadoras de Carnes [ABIEC]. (2023). *Beef report 2023: perfil da pecuária no Brasil*. ABIEC. Retrieved from https://www.abiec.com.br/publicacoes/beef-report-2023-capitulo-01/

Befort, N. (2020). Going beyond definitions to understand tensions within the bioeconomy: The contribution of sociotechnical regimes to contested fields. *Technological Forecasting and Social Change, 153*, 119923. DOI: https://doi.org/10.1016/j.techfore.2020.119923

Benez, S. M. (2002). *Manual de homeopatia veterinária: indicações clínicas e patológicas – teoria e prática*. São Paulo, SP: Robe Editorial.

Birner, R. (2018). Bioeconomy concepts. In I. Lewandowski (Eds.)*, Bioeconomy: shaping the transition to a sustainable, biobased economy* (p. 17-38). Cham, CH: Springer.

Boldrini, I. I., Overbeck, G. E., & Trevisan, R. (2015). Biodiversidade de plantas. In V. P. Pillar, & O. Lange (Eds.)*, Os campos do sul* (p. 53-62). Porto Alegre, RS: Rede Campos Sulinos/ UFRGS.

Bonauiti, M. (2011). *From bioeconomics to degrowth: Georgescu-Roegen's "new economics" in Eight Essays.* London; New York: Routledge.

Bouwman, L., Goldewijk, K. K., Hoek, K. W. V. D., Beusen, A. H. W., Vuuren, D. P. V., Willems, J., … Stehfest, E. (2013). Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900-2050 period. *Proceedings of the National Academy of Sciences, 110*(52), 20882-20887. DOI: https://doi.org/10.1073/pnas.1012878108

Bugge, M. M., Hansen, T., & Klitkou, A. (2016). What is the bioeconomy? A review of the literature. *Sustainability, 8*(7), 691. DOI: https://doi.org/10.3390/su8070691

Canozzi, M. E. A., Marques, P. R., Teixeira, O. S., Pimentel, C. M. M., Dill, M. D., & Barcellos, J. O. J. (2019). Typology of beef production systems according to bioeconomic efficiency in the south of Brazil. *Ciência Rural, 49*(10), e20190030. DOI: https://doi.org/10.1590/0103-8478cr20190030

Carvalho, P. C. F., Santos, D. T., & Neves, F. P. (2007). Oferta de forragem como condicionadora da estrutura do pasto e do desempenho animal. In M. Dall'agnol, C. Nabinger, D. M. Santana, & R. J. Santos (Eds)*, Sustentabilidade produtiva do bioma pampa* (p. 23-60). Porto Alegre, RS: Gráfica Metrópole Ltda.

Dick, M., Silva, M. A., Silva, R. R. F., Ferreira, O. G. L., Maia, M. S., Lima, S. F., ... Dewes, H. (2021). Environmental impacts of Brazilian beef cattle production in the Amazon, Cerrado, Pampa, and Pantanal biomes. *Journal of Cleaner Production*, *311*. DOI: https://doi.org/10.1016/j.jclepro.2021.127750

Diáz, M. J. M., García, V. D., Ramírez, C. A., Blanco, F. P., Domenech, F. R., & Marín, A. L. M. (2020). Effects of a concentrate rich in agro-industrial by-products on productivity results, carcass characteristics and meat quality traits of finishing heifers. *Animals, 10*(8), 1311. DOI: https://doi.org/10.3390/ani10081311

Duarte, E., Fragoso, R., Smozinski, N., & Tavares, J. (2021). Enhancing bioenergy recovery from agro-food biowastes as a strategy to promote circular bioeconomy. *Journal of Sustainable Development of Energy, Water and Environment Systems, 9*(1), 1080320. DOI: https://doi.org/10.13044/j.sdewes.d8.0320

Dumont, B., Modernel, P., Benoit, M., Ruggia, A., Soca, P., Dernat, S., … Rossing, W. A. H. (2020). Mobilizing ecological processes for herbivore production: farmers and researchers learning together. *Frontiers Sustainable Food Systems, 4*, 544828. DOI: https://doi.org/10.3389/fsufs.2020.544828

Ferreira, A., Marques, P., Ribeiro, B., Assemany, P., Mendonça, H. V., Barata, A., … Gouveia, L. (2018). Combining biotechnology with circular bioeconomy: from poultry, swine, cattle, brewery, dairy and urban wastewaters to biohydrogen. *Environmental Research, 164*, 32-38. DOI: https://doi.org/10.1016/j.envres.2018.02.007

Florindo, T. J., Florindo, G. I. B. M., Talamini, E., & Ruviaro, C. F. (2017). Improving feed efficiency as a strategy to reduce beef carbon footprint in the Brazilian Midwest region. *International Journal of Environment and Sustainable Development (IJESD), 16*(4), 379-396. DOI: https://doi.org/10.1504/IJESD.2017.087260

Food and Agriculture Organization. (2021). *The State of Food Security and Nutrition in the World 2021*. Rome, IT: FAO.

Gowdy, J., & Mesner, S. (1998). The Evolution of Georgescu-Roegen's Bioeconomics. *Review of Social Economy*, *56*(2), 136–156. Retrieved from http://www.jstor.org/stable/29769942

Georgescu-Roegen, N. (1960). Economic theory and agrarian economics. *Oxford Economic Papers, 12*(1), 1-40.

Georgescu-Roegen, N. (1970). The economics of production. *American Economic Review, 60*(2), 1-9.

Georgescu-Roegen, N. (1975). Energy and Economic myths. *Southern Economic Journal,* 41, 347-381.

Georgescu-Roegen, N. (1995). *La décroissance: entropie, écologie, économie - Hardcover*. Paris, FR: Sang de la Terre.

Georgescu-Roegen, N. (2013). *O decrescimento: entropia, ecologia, economia*. São Paulo, SP: Senac.

Guedes, V. L. S., & Borschiver, S. (2005). Bibliometria: uma ferramenta estatística para a gestão da informação e do conhecimento, em sistemas de informação, de comunicação e de avaliação científica e tecnológica. *Ponto de Acesso, 6*(1), 18.

Liao, W., R. Heijungs, & Huppes, G. (2012). Thermodynamic analysis of humanenvironment systems: A review focused on industrial ecology. *Ecological Modelling*, *228*, 76-88.

Liu, J., You, L., Amini, M., Obersteiner, M., Herrero, M., Zehnder, A. J. B., & Yang, H. (2010). A high-resolution assessment on global nitrogen flows in cropland. *Proceedings of the National Academy of Sciences, 107*(17), 8035-8040. DOI: https://doi.org/10.1073/pnas.0913658107

López-Paredes, J., Jiménez-Montero, J.-A., Pérez-Cabal, M.-A., González-Recio, O., & Alenda, R. (2017). A bio-economic model to improve profitability in a large national beef cattle population. *Spanish Journal of Agricultural Research*, *15*(3), e0406. DOI: https://doi.org/10.5424/sjar/2017153-10901

Macintosh, K. A., Doody, D. G., Withers, P. J. A., McDowell, R. W., Smith, D. R., Johnson, L. T., ... McGrath, J. W. (2019). Transforming soil phosphorus fertility management strategies to support the delivery of multiple ecosystem services from agricultural systems. *The Science of the total environment*, *649*, 90–98. DOI: https://doi.org/10.1016/j.scitotenv.2018.08.272

Marques, P. R., Peripolli, V., Lampert, V. N., Dias, E. A., Pereira, G. R., Oliveira, T. E., ... Barcellos, J. O. J. (2017). A proposal for the evaluation of the bioeconomic efficiency of beef cattle production systems. *Revista Brasileira de Zootecnia, 46*(1), 65-71. DOI: https://doi.org/10.1590/S1806-92902017000100010

Mayumi, K. (2009). Nicholas Georgescu-Roegen: His bioeconomics approach to development and change. *Development and Change*, *40*(6), 1235-1254.

Mazoyer, M., & Roudart, L. (2009). *História das agriculturas no mundo: do neolítico à crise contemporânea*. São Paulo, SP: Unesp/Nead.

Mohammadian, M. (2003). What is bioeconomics: biological economics? *Journal of Interdisciplinary Economics, 14*(4), 319-337. DOI: https://doi.org/10.1177/02601079X03001400401

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS medicine*, *6*(7), e1000097. DOI: https://doi.org/10.1371/journal.pmed.1000097

Mougenot, B., & Doussoulin, J.-P. (2021). Conceptual evolution of the bioeconomy: a bibliometric analysis. *Environment, Development and Sustainability, 24*, 1031-1047.DOI: https://doi.org/10.1007/s10668-021-01481-2

Muñoz-Ulecia, E., Bernués, A., Briones-Hidrovo, A., Casasús, I., & Martín-Collado, D. (2023a). Dependence on the socio-economic system impairs the sustainability of pasture-based animal agriculture. *Scientific Reports, 13*, 14307. DOI: https://doi.org/10.1038/s41598-023-41524-4

Muñoz-Ulecia, E., Bernués, A., Briones-Hidrovo, A., Franzese, P. P., Buonocore, E., Santagata, R., ... Martín-Collado, D. (2023b). An increased dependence on agricultural policies led European grazing agroecosystems to an unsustainability trap. *Communications Earth & Environment, 4*(269). DOI: https://doi.org/10.1038/s43247-023-00933-z

Newman, M. E. J. (2005). Power laws, pareto distributions and zipf's law. *Contemporary Physics, 46*(5), 323-351. DOI: https://doi.org/10.1080/00107510500052444

Nichele, E. M., Moraes, E. H. B. K., Araújo, C. V., Pina, D. S., Moraes, K. A. K., & Hoffmann, A. (2015). Eficiência bioeconômica de bovinos de corte em confinamento. *Revista Brasileira de Saúde e Produção Animal, 16*(3), 699-711. DOI: https://doi.org/10.1590/S1519-99402015000300020

Oaigen, R. P., Barcellos, J. O. J., Christofari, L. F., Braccini Neto, J., Oliveira, T. E., & Prates, Ê. R. (2008). Melhoria organizacional na produção de bezerros de corte a partir dos centros de custos. *Revista Brasileira de Zootecnia, 37*(3), 580-587. DOI: https://doi.org/10.1590/S1516-35982008000300025

Odum, H. T. (1996). *Environmental accounting: emergy and environmental decision making*. New York, NY: Jhon Wiley & Sons.

Organization for Economic Cooperation and Development [OECD]. (2009). The bioeconomy to 2030: designing a policy agenda. Retrieved from https://read.oecd-ilibrary.org/economics/the-bioeconomy-to-2030/executive-summary_9789264056886-2-en

Paarlberg, R. (2009). The ethics of modern agriculture. *Society, 46*, 4–8.
DOI: https://doi.org/10.1007/s12115-008-9168-3.

Pazdiora, R. D., Resende, F. D., Faria, M. H., Siqueira, G. R., Almeida, G. B. S., Sampaio, R. L., … Prietto, M. S. R. (2013). Animal performance and carcass characteristics of Nellore young bulls fed coated or uncoated urea slaughtered at different weights. *Revista Brasileira de Zootecnia, 42*(4), 273-283. DOI: https://doi.org/10.1590/S1516-35982013000400007

Reinheimer, H. (1913). *Evolution by cooperation. A study in bio-economics*. London, GB: Kegan Paul & Company.

Reis, J. C., Rodrigues, G. S., Barros, I., Rodrigues, R. A. R., Garrett, R. D., Valentim, J. F., … Smukler, S. (2021). Integrated crop-livestock systems: a sustainable land-use alternative for food production in the Brazilian Cerrado and Amazon. *Journal of Cleaner Production, 283*, 124580. DOI: https://doi.org/10.1016/j.jclepro.2020.124580

Rice, P., O'brien, D., Shalloo, L., & Holden, N. M. (2017). Evaluation of allocation methods for calculation of carbon footprint of grass-based dairy production. *Journal of Environmental Management, 202*(Part 1), 311-319. DOI: https://doi.org/10.1016/j.jenvman.2017.06.071

Rótolo, G. C., Rydberg, T., Lieblein, G., & Francis, C. (2007). Emergy evaluation of grazing cattle in Argentina's Pampas. *Agriculture, Ecosystems & Environment, 119*(3-4), 383-395. DOI: https://doi.org/10.1016/j.agee.2006.08.011.C.M.V.B

Santana, R. A. V., Barbosa, R. A., Mandarino, C. F., & Lobo, C. F. (2013). Bioeconomic performance of intensive breeding systems and of full-cycle by way of simulation. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, *65*, 1773-1782. DOI: https://doi.org/10.1590/S0102-09352013000600027

Savian, J. V., Schons, R. M. T., Marchi, D. E., Freitas, T. S., Silva Neto, G. F., Mezzalira, J. C., … Carvalho, P. C. F. (2018). *Rotatinuous stocking*: a grazing management innovation that has high potential to mitigate methane emissions by sheep. *Journal of Cleaner Production, 186*, 602-608. DOI: https://doi.org/10.1016/j.jclepro.2018.03.162

Sessim, A. G., Oliveira, T. E., López-González, F., Freitas, D. S., & Barcellos, J. O. J. (2020). Efficiency in cow-calf systems with different ages of cow culling. *Frontiers in Veterinary Science, 7*. DOI: https://doi.org/10.3389/fvets.2020.00476

Silva, P. H. F., Carvalho, C. A. B., Malafaia, P., Garcia, F. Z., Peres, A. A. C., Souza, P. M., … Ferreira, R. L. (2019). Análise bioeconômica de períodos de suplementação proteico-energética na estação seca para novilhas Nelore em pastagem diferida de *Urochloa decumbens*. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 71*(3), 1058-1066. DOI: https://doi.org/10.1590/1678-4162-10511

Smith, O. M., Kennedy, C. M., Owen, J. P., Northfield, T. D., Latimer, C. E., & Snyder, W. E. (2019). Highly diversified crop–livestock farming systems reshape wild bird communities. *Ecological Applications, 30*(2), e02031. DOI: https://doi.org/10.1002/eap.2031

Souza Filho, W., Nunes, P. A. A., Barro, R. S., Kunrath, T. R., Almeida, G. M., Moraes Genro, T. C., … Carvalho, P. C. F. (2019). Mitigation of enteric methane emissions through pasture management in integrated crop-livestock systems: trade-offs between animal performance and environmental impacts. *Journal of Cleaner Production, 213*, 968-975. DOI: https://doi.org/10.1016/j.jclepro.2018.12.245

Tanure, S., Nabinger, C., & Becker, J. L. (2013). Bioeconomic model of decision support system for farm management. Part I: Systemic conceptual modeling, *Agricultural Systems*, *115*, 104-116. DOI: https://doi.org/10.1016/j.agsy.2012.08.008.

Tilica, E. (2021). Bioeconomy and bioeconomics: are they the same thing? *International Journal of Innovative Technologies in Economy, 1*(33), 1-11. DOI: https://doi.org/10.31435/rsglobal_ijite/30032021/7470

Van Eck, N. J., & Waltman, L. (2019). *Manual for VOSviewer version 1.6.13*. Leiden, NL: Universiteit Leiden.

Vivien, F.-D., Nieddu, M., Befort, N., Debref, R., & Giampietro, M. (2019). The hijacking of the bioeconomy. *Ecological Economics, 159*, 189-197. DOI: https://doi.org/10.1016/j.ecolecon.2019.01.027

Wang, X., Wu, X., Yan, P., Gao, W., Chen, Y., & Sui, P. (2016). Integrated analysis on economic and environmental consequences of livestock husbandry on different scale in China. *Journal of Cleaner Production, 119*, 1-12. DOI: https://doi.org/10.1016/j.jclepro.2016.01.084

Wu, X., Wu, F., Tong, X., & Jiang, B. (2013). Emergy-based sustainability assessment of an integrated production system of cattle, biogas, and greenhouse vegetables: Insight into the comprehensive utilization of wastes on a large-scale farm in Northwest China. *Ecological Engineering, 61*(Part A), 335-344. DOI: https://doi.org/10.1016/j.ecoleng.2013.09.060

Zawojska, A., & Siudek, T. (2016). Bioeconomics as an interdisciplinary science. *International Conference "Economic Science For Rural Development", 41*, 273-280.