Sustainability indicators in beef slaughterhouses: a systematic review

Indicadores de sustentabilidade em frigoríficos bovinos: uma revisão sistemática

Indicadores de sostenibilidad en frigoríficos de vacuno: una revisión sistemática

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Daniel Lucas Prudencio
Master's student in Sustainable Technologies
Institution: Instituto Federal do Espírito Santo (IFES)
Address: Vitória – Espírito Santo, Brazil
E-mail: daniellucas.p@outlook.com

Adriana Marcia Nicolau Korres
Doctor in Biotechnology
Institution: Instituto Federal do Espírito Santo (IFES)
Address: Vitória – Espírito Santo, Brazil
E-mail: adrianak@ifes.edu.br

André Assis Pires
Doctor in Plant Production
Institution: Instituto Federal do Espírito Santo (IFES)
Address: Vila Velha – Espírito Santo, Brazil
E-mail: andre.pires@ifes.edu.br

ABSTRACT
The sustainable management of slaughterhouses follows market demands. The article reports a systematic literature review on the environmental impacts of beef slaughterhouses, using the PRISMA method. The review highlights the use of analytical hierarchy (AHP), greenhouse gas (GHG) emissions assessment, and life cycle assessment (LCA). The studies used the Analytical Hierarchy Process (AHP) to evaluate sustainability in the supply chain and meat production, highlighting the preponderance of economic criteria over social and environmental aspects. They identified crucial indicators such as industry diversity and energy consumption, highlighting the need for a balanced approach that considers these different aspects to achieve sustainability. The life cycle assessment focused on reducing the water footprint and greenhouse gas emissions, with the potential for mitigation through the recovery of by-products in slaughterhouses. The study showed importance of maximizing the use of slaughtered animals to reduce the environmental footprint, identifying fossil fuels as the main contributors to climate change and recommending the transition to organic agriculture as a strategy to reduce emissions. After screening, 14 were selected and, finally, 7 works were included. It also showed the low number of bibliographic
materials on sustainability indicators in beef slaughterhouses and pointing out the need for more research in this field, implementation of sustainable practices in beef production, with special emphasis on the incorporation of ESG indicators to ensure an approach aligned with the global sustainability demands.

Keywords: cattle slaughterhouses, sustainability, environmental indicators, ESG, socio-environmental impacts.

RESUMEN
La gestión sostenible de los mataderos responde a las exigencias del mercado. El artículo reporta una revisión sistemática de la literatura sobre los impactos ambientales de los mataderos de carne vacuna, utilizando el método PRISMA. La revisión destaca el uso de la jerarquía analítica (AHP), la evaluación de las emisiones de gases de efecto invernadero (GEI) y la evaluación del ciclo de vida (LCA). Los estudios utilizaron el Proceso de Jerarquía Analítica (AHP) para evaluar la sostenibilidad en la cadena de suministro y la producción de carne, destacando la preponderancia de los criterios económicos sobre los aspectos sociales y ambientales. Identificaron indicadores cruciales como la diversidad de la industria y el consumo de energía, destacando la necesidad de un enfoque equilibrado que considere estos diferentes aspectos para lograr la sostenibilidad. La evaluación del ciclo de vida se centró en la reducción de la huella hídrica y las emisiones de gases de efecto invernadero, con potencial de mitigación mediante la recuperación de subproductos en los mataderos. Se destacó la importancia de maximizar el uso de animales sacrificados para reducir la huella ambiental, identificando los combustibles fósiles como los principales...
contribuyentes al cambio climático y recomendando la transición a la agricultura orgánica como estrategia para reducir las emisiones. Tras la proyección, se seleccionaron 14 y, finalmente, se incluyeron 7 obras. También mostró el bajo número de materiales bibliográficos sobre indicadores de sostenibilidad en los frigoríficos de vacuno e señalando la necesidad de mayor investigación en este campo, implementación de prácticas sostenibles en la producción de carne vacuna, con especial énfasis en la incorporación de indicadores ESG para asegurar un enfoque alineado con las demandas de sostenibilidad global.

**Palabras clave:** mataderos de ganado, sostenibilidad, indicadores ambientales, ESG, impactos socioambientales.

1 INTRODUCTION

The production of cattle slaughterhouses is of great importance for Brazil’s economy because the country is the main world beef exporter, with 29,947,584 heads slaughtered in 2022 (IBGE, 2023a). The country has the largest cattle herd in the world, with 224,602,112 animals in 2021, a fact that has led to concern about environmental, social and governance issues (IBGE, 2023b). As society demands greater corporate responsibility and sustainability, companies in the meatpacking sector face the challenge of evaluating environmental aspects and impacts.

Considering the importance of beef slaughterhouses for sustainability, the market has increased its demands. One example is the European Parliament Resolution that prohibits the import of products, including meat, from deforested areas, and the demand from the Federation of Brazilian Banks (FEBRABAN) for more transparency and responsibility in all aspects of slaughterhouse operations (EUROPA, 2023; FEBRABAN, 2023). This includes, in particular, compliance with safety, environmental and labor standards.

In this scenario, companies in the meat production sector are adapting the growing demands of society, making the integration of sustainability indicators increasingly essential. Sustainability has become an undeniable priority in the contemporary business environment, leading meatpackers to incorporate these principles directly into their corporate strategies. This paradigm shift is reflected in the evaluation of financing and exports, which goes beyond financial metrics and meat quality, requiring continuous improvement in performance in relation to sustainability indicators (Porter; Krmer; Serafim, 2019). Thus, demanding from companies a constant evolution of performance in environmental indicators.

The Sustainable Development Goals (SDGs) are a series of global goals designed to
address socioeconomic and environmental challenges, promoting sustainable development in a
global level (UNEP, 2015). Monitoring environmental indicators ensures that the actions can
effectively reflect the sustainability of companies and that their performance promotes the global
sustainability established by the Sustainable Development Goals (SDGs) (Delgado-Ceballos et al., 2023). Sustainable practices in slaughterhouses meet the requirements of SDG 2, SDG 6, SDG 12 and SDG 13, considering that its measures practices aim sustainable food production, efficient use of water resources, reduction of environmental impacts and promotion of a more efficient production chain (UNEP, 2015).

Furthermore, evaluating the sustainability indicators of meatpacking companies is extremely important, as these organizations can have significant impacts on the environment, local communities and corporate governance (Pedersen; Fitzgibbons; Pomorski, 2021).

Given the complexity and growing relevance of sustainability today, this research undertakes a Systematic Literature Review (RSL) focusing on sustainability indicators associated with beef slaughterhouses, aiming an in-depth diagnosis of the challenges and advances in this crucial sector, carried out on the 6th of January 2024, providing valuable insights to promote more sustainable and responsible practices in the beef processing industry.

2 THEORETICAL REFERENCE

2.1 PRODUCTION PROCESS IN BEEF SLAUGHTERHOUSE

According to the Food and Agriculture Organization of the United Nations (FAO), slaughterhouses play a very important role in the food industry, which is the production of meat and its derivatives for human consumption, producing around 72,647 kt per year worldwide (FAO, 2021). The production process encompasses technology, hygiene, logistics and legislation that generates quality food, regulated by a series of health standards designed to provide consumers food security of these products (Block et al., 2016). Therefore, establishments in the meat and meat products sector in good standing work with continuous inspection and inspection by the bodies responsible for health surveillance.

In a beef slaughterhouse, the slaughter and meat processing is meticulously carried out to guarantee the quality and safety of the product. It begins with the careful selection of animals for
slaughter, followed by humane steps of stunning and removing blood to minimize suffering. After slaughter, the carcasses are deboned and cut, carried out by skilled professionals to create specific cuts and by-products (Trecenti, 2013). Meat is stored in cold rooms under strict temperature control to prevent the development of bacteria (Guzmán et al., 2021).

Some meatpacking plants also perform additional processing to create products such as sausages, burgers and hams. This involves mixing ingredients, grinding, shaping and cooking, adapting to local culinary preferences and the use of modern technologies (Hernández-Guzmán et al., 2021). All products undergo quality testing before being packed and distributed, with an emphasis on transportation and logistics efficiency (Block et al., 2016).

In addition to meat, the slaughter process generated byproducts and waste, such as hides, blood, bones and fat, varies according to the region and the availability of specialized companies. For example, blood can be processed for use in the production of animal feed or for the delivery of components such as plasma, albumin, and fibrin (Block et al., 2016). Meat production in slaughterhouses is a process that presents some challenges related to sustainability, work safety and animal welfare (Trecenti, 2013).

When relating beef processing plants and the meat supply chain, many studies identify this sector as one of the main environmental polluters in the food system. Companies that produce beef protein have high environmental impacts on air, water and soil, in addition to high consumption of natural resources such as water and energy (Castro, 2023). Slaughtering and meat processing also put pressure on the environment due to the consumption of natural resources. One of the impacts that draws the most attention is the gas emission that have the potential for global warming (Djekic; Tomasevic, 2016). The high demand for hygiene in slaughterhouses results in a high amount of water consumed, around 2,500 L/animal slaughtered (Gomides et al., 2023). Furthermore, it leads to substantial use of chemicals to perform cleaning and sanitization (Henchion et al., 2014). Consequently, high water consumption generates a large volume of effluents, with 80 to 95% of the water consumed being generated as liquid effluent (Broom, 2021). These wastewaters are characterized by a high concentration of pollutants (Allievi et al., 2015). Regarding refrigerator waste, if not managed correctly, it can cause serious environmental problems, since most of it is subject to putrefaction (Djekic et al., 2018). Another fact is that the operations of cold storage companies lead to substantial use of electricity due to refrigeration and the operation of machines and equipment (Djekic; Tomasevic, 2016).
Searching for improvements in these aspects, companies in the sector have been adopting the efficient use of natural resources, waste management and compliance with stricter regulations.

Thus, slaughterhouses represent an extremely important part of the Brazilian food industry, transforming animals into a variety of products (Trecenti, 2013). The success of the production process depends on the combination of technologies, human skills, work safety and quality, generating food that will be available to consumers.

2.2 THE ENVIRONMENTAL, SOCIAL AND ECONOMIC IMPACTS OF BOVINE SLAUGHTERHOUSES

The meatpacking industry is of paramount importance in food production, providing meat to millions of people around the world. Beef production is not exempt from significant impacts, covering environmental, social and economic aspects (Berton et al., 2017). Analyzing these three dimensions is relevant to understand how these companies operate.

The meatpacking industries have significant environmental, social and economic aspects and impact due to the high use of natural resources, income generation and social well-being (Callaway; Lorenzo, 2020).

The beef production chain uses a high amount of water, animal feed and pastures for livestock farming (Djekic, 2016). Additionally, slaughterhouses emit greenhouse gases, due to the high energy consumption in the facilities, waste management, effluents and by-products generated (Coimbra 2022). In the production of bovine protein, large amounts of waste and by-products are generated in slaughterhouses, which, if not properly managed, can cause high environmental impacts on soil and water (Speranza, 2023).

In the slaughtering and deboning process, large quantities of organic waste are generated, such as bones, skin, fat, blood and feces. If not managed, inadequate disposal can cause impacts, causing negative effects on the quality of natural resources and human health. Additionally, the decomposition of these organic refrigerator wastes generates greenhouse gas emissions, leading to an increase in global warming (Pereira et al., 2018).

The meatpacking industry also generate wastewater contaminated with blood, fat and chemicals used in the cleaning and disinfection process. If this wastewater is improperly
disposed, it can cause water pollution and affect aquatic ecosystems, reducing water quality and harming aquatic life.

Effective management of refrigerator waste is a challenge for companies in the sector. Incorrect disposal can cause environmental and public health risks, following strict regulatory actions and responsible management practices. Incineration, composting and biomethanization are alternatives to minimize the negative impacts of waste (Block et al., 2016).

An alternative to waste management in slaughterhouses is sustainability in waste management. There are several alternatives for disposing organic waste and by-products generated, such as recycling, organic fertilizer or reuse of meat, bones, feathers, offal and even blood as supplements for animal feed, reducing the amount of waste sent to landfills (Salomão, Farias; Esturaro, 2018).

In the social sphere, there are positive and negative impacts on meat production. Meat processing plants offer employment opportunities for communities and generate taxes for the State (Burnier et al., 2021).

On the economic side, meatpacking plants are important for tax revenue and the development of local economies. In addition to being a catalyst for local development, the meat processing industry is a significant source of revenue for several countries (Djekic, 2018).

Therefore, it is extremely important to balance sustainability in slaughterhouses, combining food production, environmental sustainability, social well-being and economic viability. Understanding and seeking control with sustainable technologies is of paramount importance to ensure the continuous production of quality food with sustainable use of natural resources, social justice and economic balance.

3 METHODOLOGY

Initially, a Systematic Literature Review (RSL) was carried out on January 6, 2024, with a Snowball sampling, seeking to understand the sustainability indicators of slaughterhouses. The use of RSL is justified by the need to find all available evidence on the topic in question, allowing a more complete assessment of the subject (Torgerson, 2003). Snowball sampling was used to expand the scope of the research, identifying relevant publications that fit the research objective, but not identified by RSL (Wasserman; Faust, 1994). The RSL was conducted according to the
Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Liberati et al., 2009), which consists of a four-step approach, namely: identification, screening, eligibility and inclusion. The activities developed at each stage of the RSL are illustrated in Figure 1.

![Systematic review steps](image-url)

Source: Prepared by the authors themselves.
The first stage, identification, was characterized by defining the research problem, thematic axes and search string. This research addresses the topic of environmental indicators in slaughterhouses with the aim of answering the following question: “What are the sustainability indicators of beef slaughterhouses?” To this end, five thematic axes for the research were defined, namely: sustainability; slaughterhouse; beef; indicators; ESG. For each thematic axis, terms were defined based on the descriptors used in scientific articles referring to the topic.

Based on the terms, specific search strings were developed for the chosen database, using Boolean logical operators to restrict and refine the results. The research was carried out in the Scopus database, as it is considered a broad and widely used database. From the results, the type of document (articles and works published in event annals) and language (Portuguese and English) were filtered. The time horizon was 10 years in this research, from 2014 to 2024.

The second stage, screening, consisted of reading the title, abstract and keywords of the studies by the search string, selecting only publications with inclusion and exclusion criteria defined for the study (Chart 1). If there were doubts about including a study in the proposed topic, it was selected for the next full reading phase. This step was carried out with the help of the Mendeley reference manager, with the results organized in spreadsheets on Microsoft Excel software.

The third stage, eligibility, was characterized by the complete reading of the work, seeking to identify sustainability indicators in beef slaughterhouses. During the complete reading of the studies, were re-evaluated as to whether they had inclusion and exclusion criteria (Chart 1).

Chart 1. Inclusion and exclusion criteria for articles from the systematic review

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<th>CI1</th>
<th>CI2</th>
<th>CI3</th>
<th>CE1</th>
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<tbody>
<tr>
<td>Scientific articles published in journals and publications at events</td>
<td>Text in English or Portuguese</td>
<td>Built and/or applied sustainability indicators related to cattle slaughterhouses</td>
<td>Theoretical or non-theoretical publications address the sustainability indicators of beef slaughterhouses</td>
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Source: Prepared by the authors themselves.

The last stage, inclusion, was the final selection of studies for analysis. Based on the results, the Snowball method was applied based on the methodology of (Wasserman; Faust, 1994). This method aims to identify works that were included in the references of selected publications and that were not identified by the search string, being included in the selected works.
and also evaluated for compliance with the inclusion and exclusion criteria. The results were organized on Microsoft Excel software. This step was essential to understand the existing literature on the topic and select environmental indicators in beef slaughterhouses for the study. The environmental indicators of the slaughterhouses were selected based on the results obtained from the RSL, seeking an objective view of sustainable practices related to the selected indicators (Susanty et al., 2021).

4 RESULTS AND DISCUSSIONS

In the systematic review, in the initial identification stage, 48 studies were found. When going through the RLS phases, in the end it reached 7 works (Figure 2).

Figure 2. Results of the RLS stages

Source: Prepared by the authors themselves.

The types of documents found were identified: publication of events (1) and scientific articles (6) (Figure 3).
The data (Figure 4) points to a significant increase in the number of publications in 2016. This growth can be attributed to a series of factors. First, more emphasis to the UN Sustainable Development Goals (SDGs), Environmental, Social and Governance (ESG) criteria and the need to reduce carbon emissions. Furthermore, the emergence of the climate crisis, growing market demand for sustainable investments and greater consumer awareness regarding sustainability may also have contributed to this increase (IPCC, 2015).
Regarding language, the results show that all documents are in English (Figure 5). Periodical publications in the English language are relevant because it is a widely used language with a worldwide reach.

The studies found in RSL showed that the articles collected used different methods of studying sustainability indicators (Figure 5), four articles were life cycle assessment, one on the assessment of greenhouse gas (GHG) emissions and two analytical hierarchy (AHP). However, no study used Environmental, social and governance (ESG) recommended practices, considering that they are increasingly recommended due to their growing global importance, including in the specific context of Brazil, reflecting a commitment to sustainability and responsibility corporate (Pérez et al., 2022).

There are some possible justifications for the reduced number of research on ESG (Environmental, Social and Governance). The first is the newness of the term: ESG was coined in 2005 and has only recently gained popularity (Pérez et al., 2022). As an example, internet searches for the term “ESG” grew five times since 2019 and more than 1200% in Brazil in the last two years (2022 and 2023) (EXAME, 2023). Another factor is the change in focus: previously, the emphasis was on Corporate Social Responsibility (CSR), which reflected more corporate engagement than changes in the core business model (Pérez et al., 2022). Furthermore, there are implementation challenges: some companies may face difficulties implementing the ESG agenda due to internal conflicts or lack of clarity about what to measure (Spitzeck, 2022). Finally, there are doubts about the integrity of ESG investments: there are questions about the effectiveness and authenticity of investments made in ESG (Pérez et al., 2022). Despite these challenges, it is important to highlight that interest in ESG has grown rapidly, both in terms of internet research and implementation in companies.
In Huerta's work; Guereca; Lozano (2016) evaluated the life cycle of beef, where he observed the environmental impacts of producing 1 kg of beef throughout the entire production chain. The environmental indicators of thermal energy sources, global warming potential (GWP), acidification potential (PA), eutrophication potential (PE) and photochemical ozone creation potential were evaluated. The results showed that in processing, eleven of the twelve impact categories analyzed, the main contributor to climate change is the use of fossil fuels and the formation of photochemical oxidants. The work contributes to the understanding of environmental impacts throughout the production chain, connecting to SDGs such as 12 and 13. This analysis addresses fundamental environmental issues, such as acidification and eutrophication, aligning with ESG principles.

Susanty et al. (2019) study used the analytical hierarchy (AHP), analyzed environmental, social and economic themes, demonstrating a comprehensive ESG approach, reflecting the alignment with several SDGs, such as SDG 5, SDG 6, SDG 7, SDG 8 and SDG 12, highlighting the importance of economic and social sustainability in meat production, which analyzed 11 indicators used, such as productivity, gross value added per workforce (ECO 1), diversity and structure of the industry, percentage of large-scale farmers (ECO2), self-sufficient, realizes.
5 CONCLUSION

The search for the PRISMA method is safe and reliable and allows the survey and organization of studies on the topic. An obstacle is still the low number of bibliographic materials found in research into sustainability indicators in beef slaughterhouses.

It is observed that sustainability indicators in beef slaughterhouses constitute a potential to be explored in carrying out sustainable actions in environmental, economic and social aspects. Scientific research that addresses the topic can contribute to greater sustainability in meat producing companies.

The sustainability index, life cycle assessment, greenhouse gas emission and analytical hierarchy (AHP) methods address essential strategic indicators in the assessment of sustainability in beef production.

The studies applied the Analytical Hierarchy Process (AHP) to assess sustainability in the livestock supply chain and meat production. They highlighted the importance of economic criteria over social and environmental criteria, on the other hand, they identified the diversity and structure of the industry, energy consumption and the number of employees per company as the most important indicators. The studies reflect the need for a balanced and comprehensive approach to achieve sustainability, considering economic, social and environmental aspects. The life cycle assessment focuses on specific improvements, highlighting indicators such as water footprint, greenhouse gas emissions and natural resource consumption throughout the product's life cycle and use of non-renewable energy, identifying on farms the greatest part of emissions, with the potential for reduction through the recovery of by-products in slaughterhouses. The study highlights the need to maximize the use of slaughtered animals to reduce the environmental footprint. It identified the use of fossil fuels as the main contributor to climate change. Recommends transitioning to organic agriculture as a means of reducing emissions. Thus, each method offers a unique approach to capturing strategic indicators, providing a more complete and detailed understanding of sustainability-related challenges and opportunities in the beef industry.

Despite not mentioning SDGs and ESG, the studies provide a holistic approach aligned with ESG principles, contributing to the understanding and practical application of SDGs in beef production.
In summary, the review highlights the need for research and implementation of sustainable practices in beef production, with emphasis on the incorporation of ESG indicators to ensure a truly holistic approach aligned with global sustainability demands.

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