Original Article

Assessment of the sustainability of the swine supply chain

Avaliação da sustentabilidade na cadeia produtiva de suínos

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ABSTRACT

Purpose: Among the production chains, the pig farming supply chain stands out. The study aims to identify the level of sustainability in the swine production chain based on the analysis of externalities, considering the criteria of the System of Management and Assessment of Sustainability of Pig Farming.
Design/methodology/approach: The case study is carried out at a rural property in the municipality of Herval D'Oeste-Santa Catarina, the research is descriptive with qualitative analysis. For the development of the research, the information about the productive process was identified through interviews, the structured script allowed for identification of about 60 metrics and external indicators of the social, environmental, and economic-financial dimensions.
Findings: The economic-financial dimension presented the remuneration of labor and invested capital as positive externalities. The social performance indicators (social interaction, human capital, and environmental practices) showed compliance levels in the model. Based on the analysis, negative externalities were identified in the environmental assessment indicators of water, air/greenhouse effect, and energy, highlighting the need for improvements in the production process and in the management of natural resources.
Practical implications: The model contributes to the evaluation of production practices and indicates weaknesses and needs for improvements in the management of the pork supply chain.
Social implications: The results demonstrate the importance of assessing sustainability in rural areas, considering it relevant link in the production chain.
Originality/value: The analysis highlights the importance of assessing sustainability in supply chains, aiming to correct the negative externalities of the production process of rural activities.

Keywords: Sustainable supply chain management; Swine supply chain; Sustainability indicators

RESUMO

Objetivo: Dentre as cadeias produtivas, destaca-se a cadeia produtiva da suinocultura. O estudo tem como objetivo identificar o nível de sustentabilidade na cadeia produtiva da suinocultura a partir da análise de externalidades, considerando os critérios do Sistema de Gestão e Avaliação da Suinocultura em Sustentabilidade-Web.

Desenho/metodologia/abordagem: O estudo de caso é realizado em uma propriedade rural no município de Herval D'Oeste-Santa Catarina, a pesquisa é descritiva, com análise qualitativa. Para o desenvolvimento da pesquisa, as informações do processo produtivo foram identificadas por meio de entrevistas, o roteiro estruturado permitiu identificar cerca de 60 métricas e os indicadores de externalidade das dimensões social, ambiental e econômico-financeira.

Resultados: A dimensão econômico-financeira apresentou a remuneração do trabalho e o capital investido como externalidades positivas. Os indicadores de desempenho social (interação social, capital humano e práticas ambientais) apresentaram níveis de conformidade no modelo. Com base na análise, foram identificadas externalidades negativas nos indicadores de avaliação ambiental de água, ar/estufa e energia, evidenciando a necessidade de melhorias no processo produtivo e na gestão dos recursos naturais.

Implicações práticas: O modelo contribui para a avaliação das práticas produtivas, aponta fragilidades e necessidades de melhorias na gestão da cadeia produtiva da carne suína.

Implicações sociais: Os resultados demonstram a importância de se avaliar a sustentabilidade no meio rural, considerando-a como um elo relevante da cadeia produtiva.

Originalidade/valor: A análise destaca a importância de avaliar a sustentabilidade nas cadeias produtivas, visando corrigir as externalidades negativas do processo produtivo das atividades rurais.

Palavras-chave: Gestão da cadeia de suprimentos sustentável; Cadeia produtiva de suínos; Indicadores de sustentabilidade

1 INTRODUCTION

Brazilian agribusiness stands out on the national scene, because even in times of crisis, it remains one of the most important sectors of the Brazilian national economy, with a relevant participation in the Gross Domestic Product (GDP) (Zanin, Kruger, Silveira & Eduardo, 2022). In 2020 it represented 26.6% of the Brazilian GDP, reaching the value of almost R$ 2 trillion (Confederation of Agriculture and Livestock of Brazil, 2021). Among the predominant activities in Brazilian agribusiness, the productive chains of grains, poultry, beef and pork production stand out (Brazilian Agricultural Research Corporation, 2022).

Parallel to the growth of agribusiness, there are global concerns about sustainability, because while it is necessary to increase food production, there are

numerous concerns with social and environmental issues (Afonso, Zanin, & Durán, 2022). It should be noted that these concerns are included in the objectives established by the Sustainable Development Goals (SDGs) (Sharma, Chandna & Bhardwaj, 2017; Olsson & Kruger, 2021).

Regarding the pork production chain, these can generate significant impacts on the environment, as the focal companies concentrate many animals on a single rural property, generating a large amount of waste, which, if not disposed of correctly, is highly harmful to the environment (Camargo, Zanin, Mazzioni, Moura & Afonso, 2018). Furthermore, it is noteworthy that the efficiency of a production chain occurs when all actors (chain links) act in an articulated way, in such a way that everyone has financial gains and at the same time is held responsible for environmental damage (Zanin & Bagatini, 2012).

In this context, it is important to establish sustainability indicators aimed at continuous improvement in all actors in the chain focused on sustainable production goals (Clift, 2003). In addition, it is recommended to evaluate the economic, social, and environmental impacts, among others (Kruger, Zanin, Durán & Afonso, 2022; Kruger & Link, 2023).

Through the analysis of indicators, positive and negative impacts can be identified throughout the product life cycle and the supply chain (Khan, Zhang, Golpîra & Qianli, 2018). In particular, the environmental impacts resulting from the production and consumption of resources in the pork chain affect families, companies and society (Camargo et al., 2018). These impacts can cause effects at various levels and produce long-lasting effects that can cross the boundaries of industries and economies (Van den Bergh, 2010).

The control and measurement of such impacts must consider the balance between production, consumption, and the environment (Bithas, 2011). Therefore, it is highlighted that the relevance of evaluating productive practices, through sustainability indicators, points to methods that make it possible to correct negative impacts, by

observing the environmental, social and economic contexts (Kruger et al., 2022).

Given the above, the guiding problem of this study can be configured: What is the level of sustainability of a rural property that operates in pig production through the criteria of the System of Management and Assessment of Sustainability of Pig Farming - Sigeas? To respond to the problem, the objective is to identify the level of sustainability based on the analysis of the externalities of the pig farming activity, considering the criteria of the System for Management and Assessment of Sustainability in Pig Farming – Sigeass-Web.

In this sense, the relevance of the study is justified, aiming to contribute to discussions about the importance of sustainability analysis, considering the specificities of the three dimensions (environmental, social, and economic-financial), in order to enable improvements in the management process of the swine activity (Santiago-Brown, Metcalfe, Jerram & Collins, 2015; Kruger & Petri, 2019). As well as to minimize the negative impacts of the activity on natural resources (Franco, Gaspar, & Mesias, 2012; Sachs, Schmidt-Traub, Kroll, Durand-Delacre, & Teksoz, 2016). Performance analysis through indicators becomes relevant for the pork supply chain management (Camargo et al., 2018; Kruger et al., 2022).

Sigeass is a support system for assessing and managing the sustainability of pig production (Kruger, 2017; Kruger & Petri, 2018; Kruger & Link, 2023). In this context, the study is justified by the importance of generating specific information on the reality of each pig production farm, offering rural managers evidence about the negative externalities related to the environmental, social, and economic-financial dimensions, considering that these are weaknesses that can be improved, with the objective of correcting the negative impacts on pig farming production, to obtain a better performance in sustainability.

2 CONCEPTUAL FRAMEWORK

2.1 Sustainable Management of the Pig Farming Supply Chain

Discussions about sustainability refer to the concerns advocated by the triple bottom line, contemplating the environmental, social and economic dimensions (Elkington, 2012). In the business scenario, companies increasingly need to seek alternatives to minimize the impact of their activities (Wolffenbüttel, & Garcia, 2020; Haetinger, Rempel, Herrmann, & Silva, 2021).

Sustainability has been discussed and identified as a worldwide primary objective of companies, people, and organizations. Therefore, to align common goals, the United Nations (UN) established, in 2015, 17 goals for the sustainable development of nations, known as the 2030 agenda. Such measures, according to the UN, are a global call to end poverty, ensure peace and protect the environment and climate (United Nations, 2022).

According to Olsson and Kruger (2021) and Kruger, Wiest, Dalla Porta, & Zanella (2021), such objectives must control human actions that may be harmful in the long term and, through the 2030 agenda, it will be possible to achieve balance in the three sustainable dimensions: environmental, social and economic. Camargo et al. (2018), define the economic dimension as that which has costs, revenues and results; the environmental dimension is defined through natural resources; and, finally, the social dimension, which encompasses the human and social aspects.

The effort to reduce negative impacts on the environment and increase positive impacts on social and economic dimensions also coming from the pork production chains (Kruger et al., 2022). Santiteerakul, Sekhari, Ouzrout and Sopadang (2011) define a production chain as a set of processes that are part of the production, from the beginning to the delivery to the customer, of a given product. This set involves people, management, technology and, among other systems, also involves sustainability. Cruz, Alencar and Silva (2017) state that the greatest sustainable requirements come from

the external market, as countries are increasingly restricting imports of agribusiness products to those that comply with sustainability standards.

About sales to the foreign market, as pointed out by the Brazilian Association of Animal Protein (2022), in Brazil, pork exports grew by 17.8% compared to the last year (2021). In addition, the historical performance of pork exports always brings positive results, having a highly significant impact on the domestic market. However, to maintain the growing history of this market, actions and processes aimed at minimizing the impacts that the pork chain generates are necessary. This is because pig farming is one of the activities that generate the most negative impact on the environment, as the exposed waste can eliminate large amounts of methane gas and, therefore, pollute the environment (Zanin & Bagatini, 2012). Thus, the pork production chain needs to be prepared to meet the demands of the consumer market (Haque, Demilade & Kumar, 2022).

The use of indicators for evaluating the sustainability of pig production becomes relevant to mitigate the negative impacts of production and contribute to improvements in the management of natural resources, adding contributions in relation to the SDGs and the goals proposed by the UN Agenda 2030 (Kruger & Petri, 2019; Kruger et al., 2022).

2.2 Livestock Supply Chains

The organizations belonging to the pork supply chain, play an economically relevant role, and they are increasingly globalized and competitive. However, it is necessary to evaluate the impacts of the activity that involves the upstream and downstream links, including rural producers, suppliers, customers, transporters, agroindustry, and other services (Geng, Mansouri & Aktas, 2017; Christopher, 2017; Afonso, Zanin, & Durán, 2022).

Borlachenco and Gonçalves (2017) point out that livestock, with extensive breeding and without proper management by most producers, presents great degradation of the soil and environment. The authors point out the importance of establishing sustainable practices in the three areas of the sustainable tripod

(environmental, social and economic), using new technologies and practices that allow for equal or greater production, without increasing areas already cultivated.

It is important to emphasize that pig farming has social and economic relevance, on the generation of jobs and incomes, both in rural areas and indirectly throughout the production chain. However, the activity generates negative impacts, especially in relation to environmental aspects, such as soil, water, and air contamination, resulting from the waste generated by the production process (Camargo et al., 2018; Secco, Luz, Pinheiro, Francisco, Puglieri, Piekarski & Freire, 2020). The analysis of sustainability indicators becomes relevant, aiming to contribute to the evaluation and implementation of improvements, for sustainable development, across the chain (Kruger & Petri, 2019).

It should be noted that the leading companies in this segment experience a competitive oligopolistic market. As a result, there is a dominant focal company controlling all actors in the chain. Pork farms are among the main actors in the chain and have a heave demand to meet the indicators proposed by agroindustries.

Therefore, the comparative performance analysis between the actors is crucial, as in the past agroindustry's were heavily criticized for the negative impacts caused to the environment and society (Zanin, Magro, Mazzioni & Afonso, 2020). This chain operates vertically, and the farms operate in different stages, that is: piglet production unit, nursery and finishing. Therefore, because they have their own characteristics, where social, environmental and economic issues are different, it is essential to evaluate each one separately, as the stakeholders can also be different (Mastronardi, Marino, Aurora & Giannelli, 2015).

In this sense, the pork production chain directly contributes to sustainable development, and must have its purposes aligned with the Sustainable Development Goals (SDGs) (United Nations, 2022), because the consumer market is aware of this, not buying from companies that harm the environment and are not committed to social issues.

Previous studies have shown that the pork production chain can generate significant negative impacts on the environment, as the focal companies concentrate

the number of animals, generating a large amount of waste, which, if not properly disposed it's highly harmful to the environment (Zanin & Bagatini, 2012; Kruger & Petri, 2019; Camargo et al., 2018; Kruger et al., 2022). In this sense, the importance of sustainability assessment is highlighted, aiming at adding continuous improvements to all actors in the supply chain (Clift, 2003). In addition, it is recommended to evaluate the economic, social and environmental impacts of pig production (Kruger et al., 2021).

Finally, by improving environmental, social, and economic performance throughout the supply chain, companies can improve processes, reduce costs, increase productivity, innovate, differentiate and improve social results (Camargo et al., 2018; Zanin et al., 2020; Kruger & Link, 2023).

3 MATERIALS AND METHODS

Methodologically, the research is characterized as descriptive, carried out from a case study, with a qualitative analysis. The collection and analysis of the results were elaborated from the application of the checklist of the System of Management and Evaluation of the Sustainability of the Swine Farming (Sigeass-Web), considering as study environment a rural property of the municipality of Herval D'Oeste-Santa Catarina, which develops the swine activity in partnership with agroindustry.

Sigeass-Web is a structured model composed of the environmental, social and economic-financial dimensions, which brings together 10 performance indicators and sustainability performance assessment metrics (Kruger, 2017), enabling the disclosure of negative and positive externalities of production swine production. Sigeass-Web is a system developed with resources from the Foundation for Research and Innovation of the State of Santa Catarina (Fapesc/2021-2022).

It was observed during the selection of the study environment that the entity has about 310 sows and 700 piglets in the weaning phase (Piglet Production Unit - UPL, up to 8 kg). Embrapa (2022) defines large farms are those with 250 sows or more. Table 1 presents the main characteristics of the study environment.

Table 1 – Characteristics of the rural property

Features	Farm Videira-SC
Number of animals - total	1,010
Number of matrices	310
Employees (including managers)	3
Farm in hectares	17,5
Production system/ production link	Piglet Production Unit
Type of waste treatment system	Composter

Source: elaborated by the authors

Table 1 shows the number of animals and the size of the property in hectares (17.5). It was found that three family members are involved in the development of the swine activity, the developed production system (UPL), and the used manure treatment system.

For data collection, pre-scheduled interviews were conducted with the entity's manager in December/2022, later the data were then entered into the Sigeass-Web.

The SIGEAS System was developed by Kruger (2017), based on the Delphi technique, considering the following development stages:

a) Mapping of a set of sustainability indicators focused on pork production in the literature;

b) Validation of a set of measures to assess the sustainability of pig farming (indicators and metrics), based on interviews with 24 specialists (professionals who work in the pig production environment), weighing their perspectives on activity assessment metrics;

c) New round of questioning with the specialists through a questionnaire, aiming at qualifying the metrics and indicators of the sustainability of pork production;

d) Proposal of a set of indicators for assessing the sustainability of pig production, called SIGEASS. The model uses compensation rates considering the environmental, social and economic-financial dimensions). The upper measures represent favourable conditions (positive externalities, above 100 points), while the lower measures represent the lowest suggested level, or minimum condition for the activity, below this condition negative externalities are evident (from 0 to -200).

e) The construct was applied in different swine production environments, the analysis carried out indicated its validity and relevance in the assessment of the sustainability of swine production, as it demonstrates positive and/or negative externalities.

The use of the Delphi technique is recommended in situations where a particular observed problem can benefit from subjective judgments, and where individuals or specialists do not have a history of communicating with each other in this sense, the heterogeneity of participants must be preserved (specialists with training and experience different), aiming to guarantee the validity of the results (Linstone & Turoff, 2010).

The script of the model, structured according to Kruger (2017), uses measurement theory to build the criteria analysis and evaluation of performance indicators, as shown in Table 2.

Table 2 – Criteria used to evaluate performance indicators

| Criteria for evaluating performance indicators	
Compensation fees (linear function)	Indicate the general condition of compliance with the construct, considered 100% for cases that meet all indications/or metrics identified as superior measures. Compensation rates add up to 100% for each aspect of the assessment (environmental, social and economic-financial).
Unit	Indicative unit of analysis (%, R$, factors, meters, m³, etc.).
Superior Measures (ordinal)	Highest level - suggested as ideal, or favorable condition for the activity.
Lower Measures (ordinal)	Lower suggested level, or minimum condition for the activity, below this condition negative externalities are evident.
Superior Score	200 points
Bottom Score	-200 points
Measure (cardinal)	Identification of the condition of the rural entity, based on its environmental, social and economic-financial conditions. Identified from the structured script and the evaluation metrics identified in the Sigeass Construct.
Scoring by the Interval scale	Reflects the condition of the measures in relation to the compensation rates of each set of indicators, showing the valuation of the activity's positive or negative externalities.

Source: Kruger (2017, p. 115)

Based on the model developed by Kruger (2017) and subsequent applications, as evidenced by Kruger & Petri (2019) and Kruger et al. (2022), the set of SIGEASS indicators, evaluates the practical aspects of pork production, evidenced through externality metrics (positive or negative). The model developed by Kruger (2017) was improved in a software format, called Sigeass-Web. This study uses the software to collect and analyse the results, with the graphs generated by the system.

According to the Sigeass-Web model, measures with results below zero are considered negative externalities of swine activity. If the performance is between zero and 100 points, they are considered compliant, and when the result is higher than 100 points, they are considered positive externalities. The analysis of the results obtained from the Sigeass-Web model highlights the positive and negative externalities of pig production, enabling improvements to be made in relation to the negative externalities (Kruger, 2017). The analysis of the three dimensions of sustainability, based on the metrics and the set of indicators observed, makes it possible to assess sustainability in production chains, aiming to correct the negative externalities of the production process of pig production.

4 ANALYSIS AND DISCUSSION OF RESULTS

Through the application of the structured checklist based on the Sigeass-Web Model, it was possible to characterize the sustainable practices, as well as to identify the positive and negative externalities of the swine activity. In Figure 1, the set of environmental performance assessment elements is presented.

Figure 1 – Assessment of environmental aspects
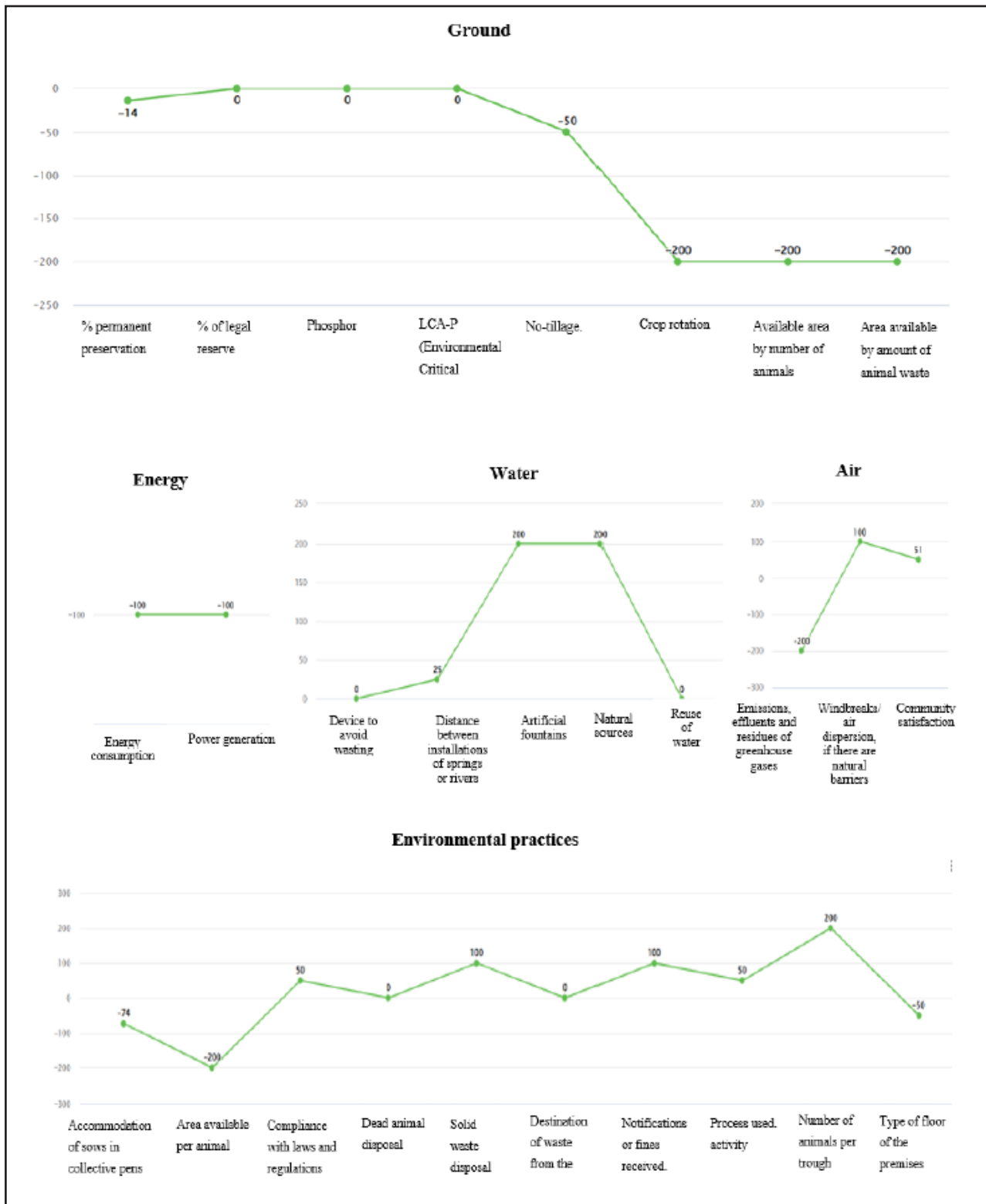
Source: elaborated by the authors

It can be seen in Figure 1 the details of the metrics for evaluating the environmental dimension, composed of the Soil, Energy, Water, Air and Environmental Practices indicators. In this sense, negative externalities are observed: percentage of permanent preservation area, direct planting, crop rotation, total own area and area available for disposal of waste, consumption and generation of energy, as well as the emission of greenhouse gases. greenhouse effect. Regarding the metrics of the environmental practice's indicator, negative externalities are observed concerning the metrics: the housing of the sows in collective pens, available area per animal and type of floor in the facilities. The use of artificial sources, natural sources and the number of animals per drinking fountain can already be observed as positive externalities. The other metrics show "neutral" performance or are considered compliance.

The environmental dimension is evaluated by a set of five indicators (soil, energy, water, air, and environmental practices. These indicators have evaluation metrics, as shown in Figure 1.

a) The soil evaluation metrics indicate the absence of adequate permanent preservation areas, as well as it was identified that direct planting (-50) does not occur as an agricultural cultivation practice. The manager indicates that he adopts crop rotation (-200), yet, the area available to dispose of waste is not enough (-200), according to the model, considering the number of housed animals (-200), so such measures represent negative externalities in the model.

b) The energy evaluation metrics show negative externalities, considering that there are no practices in the rural entity to reduce Energy Consumption, the measure is observed from the total cost of energy and efficiency of facilities due to the use of biodigesters or other technologies. Still, concerning Energy Generation, the percentage of savings generated due to improvements in the conservation and efficiency of installations, like the use of biodigesters, can be observed.

c) As for the water indicator, it was identified that there is no device on the farm

to avoid wasting water for animal consumption (0), nor does it adopt technologies for the reuse of water.

d) The air indicator has three metrics, and the measurement "Emissions, effluents and residues of greenhouse gases, by weight" considers whether there is a biodigester and methane burning occurs, minimizing the impact of greenhouse gases as a negative externality (-200). Aspects related to the existence of windbreaks and satisfaction with the community meet the criteria of the model.

e) The environmental practices indicator is composed of a set of 10 evaluation metrics, considering the aspects of housing the breeders in collective pens (-74); available area per animal (-200), floor type of the facilities (-50), representing negative externalities. The metrics discarding dead animals and the destination of waste from the activity show zero measures (0). While the solid waste disposal metrics (100), notifications or fines received (100) and number of animals per drinking fountain (200), indicate positive externalities. The metrics "compliance with laws and regulations" (50) and "used processes" (50) are suitable criteria, meeting the minimum indicated by the Sigeass model.

The findings corroborate the research by Santiago-Brown et al. (2015), highlighting the importance of environmental, social and economic analysis of the swine activity, making it possible to identify improvements to the production process, especially considering that the activity developed in the partnership system represents one of the most relevant links in the swine supply chain.

The environmental aspects observed in the model made it possible to identify the negative externalities of production, as well as being efficient in identifying environmental weaknesses, enabling the continuous evaluation of swine production practices, especially to minimize impacts on natural resources (Franco et al. al., 2012; Sachs et al., 2016; Kruger & Petri, 2019; Kruger et al., 2022).

In Figure 2 shows the set of social performance evaluation metrics.

Figure 2 – Assessment of social aspects
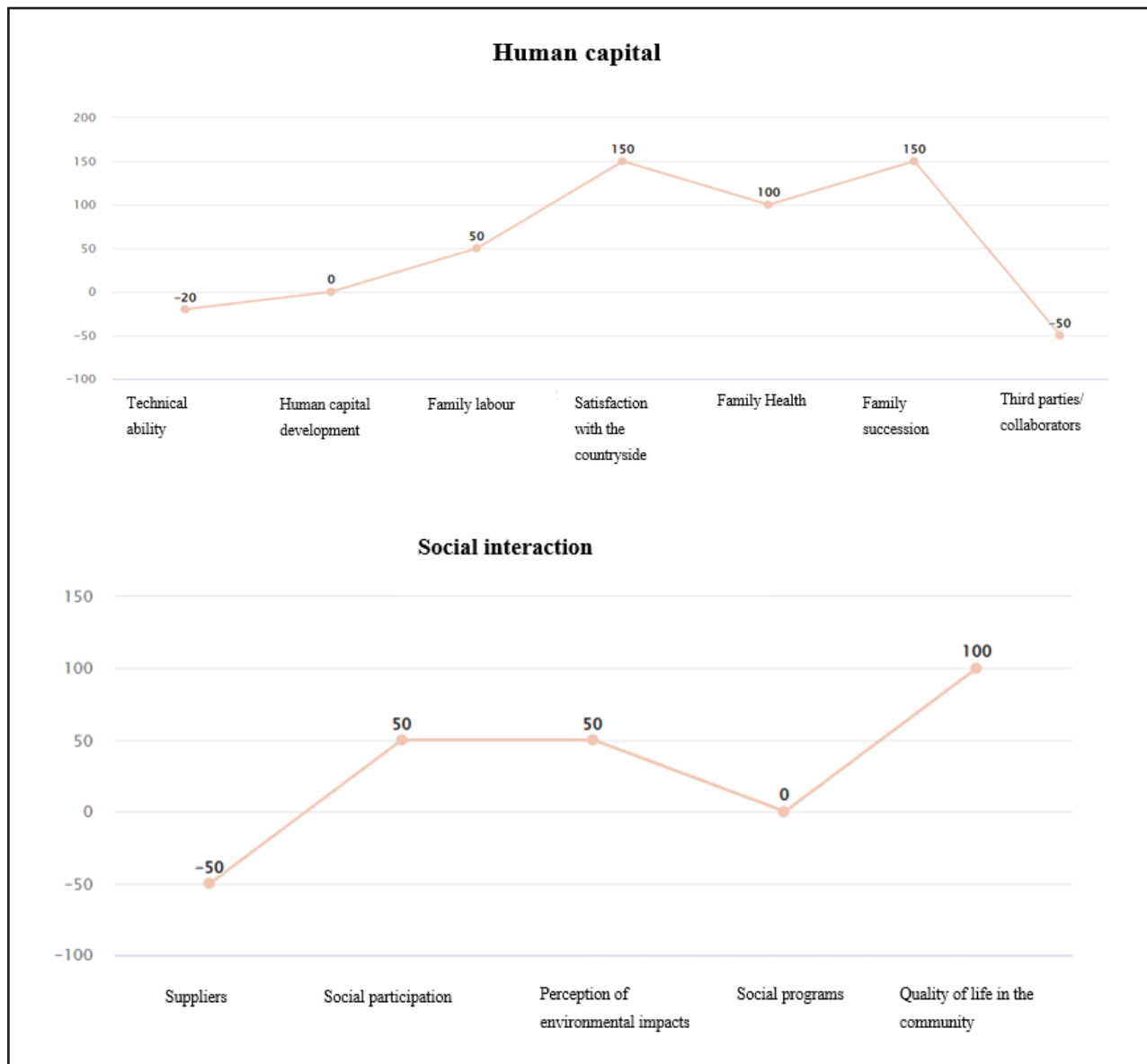
Source: elaborated by the authors

Regarding the social performance evaluation indicators (human capital and social interaction), Figure 2 shows the aspects observed by the Sigeass-Web model. Metrics related to technical capacity, third parties/collaborators and suppliers are perceived as negative externalities.

Negative externalities indicate the need for improvement, with weaknesses identified in the study environment, when the manager is asked about the "Number of hours of annual training aimed at managing the business or swine activity", the

metric is negative (-20) due to the lack of training hours. Another criterion observed is If the rural property uses third parties or collaborators, these are registered (regular work regime with a formal contract, complying with labour legislation), and the metric shows a result of -50, due to the absence of formal employment contracts.

About the supplier indicator, it was verified whether the manager considers the responsibility of suppliers in the purchase of inputs for the swine activity (factors), such as waste collection, the legality of the workforce, and instructions for use, among others. In this case, the manager does not analyse these criteria, thus showing up as a negative metric (-50).

Aspects observed as positive externalities are related to satisfaction with the rural environment and family succession (bearing in mind that there is already a successor who works in the development of the activity). The other aspects observed present compliance metrics (development of human capital, family labour, family health, social participation, perception of environmental impacts, and social programs).

Among the criteria observed in the social dimension are human capital and social interaction are observed if the family discusses the process of family succession, has children who collaborate in activities and are interested in the succession/continuity of activities. Aspects related to quality of life and satisfaction with the rural environment, social interaction and participation in the community (church, mothers' club, community services, etc.). Social interaction adds coexistence values and facilitates the well-being of the family in the community, and the more integrated into the rural environment is better.

From the model, it can be inferred that the indicators with negative performance and those with compliance weight can be improved, aiming at a better performance in sustainability, enhancing best practices related to the social aspects of the swine activity. Kruger et al. (2021) highlight the relevance of social performance indicators, especially because they reflect on the permanence and continuity of swine activity. The set of sustainability indicators is relevant to enhance the correction of weaknesses

and the implementation of improvements, in favour of the sustainable development of the pork supply chain (Franco et al., 2012; Sachs et al., 2016; Kruger et al., 2022).

After the detailed analysis of the environmental and social performance indicators, the aspects related to the economic-financial performance are observed, contemplating the indicators of remuneration of the workforce and remuneration of the invested capital. In this dimension, the results stand out as positive externalities, that is, the remuneration of the workforce is adequate and the return on invested capital occurs in the short term, reaching superior performance metrics.

Figure 3 presents the sustainability assessment of the analyzed entity, considering the environmental, social and economic-financial dimensions.

Figure 3 – Sustainability performance assessment
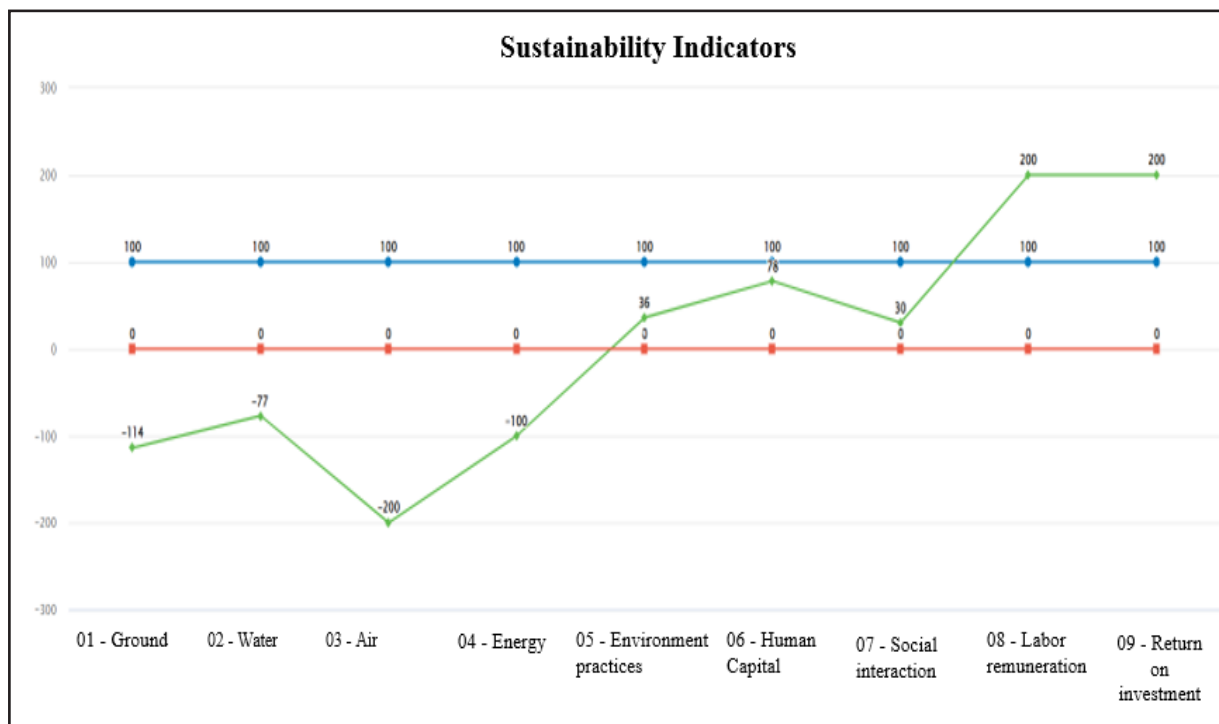
Source: elaborated by the authors

It is observed in Figure 3, the general performance in sustainability of the evaluation of the analysed rural property. The analysis demonstrates negative externalities in the soil, water, air and energy indicators (below 100 points). Positive

externalities refer to the economic and financial indicators of remuneration of labour and remuneration of invested capital (above 100 points). Also, the indicators of environmental practices, human capital and social interaction, present compliance performance metrics (between zero and 100).

The results presented in Figure 3 summarize the metrics detailed in the figures above in Figures 1 and 2, making it possible to observe the detail of the indicators and their evaluation criteria, covering more than 40 evaluation metrics in the environmental, social and economic-financial dimensions.

As a suggestion for improvements, the rural manager can propose to implement better production practices, such as capturing rainwater for reuse in the facilities, as well as analysing the viability of using a biodigester, aiming to adapt the destination of waste and minimize aspects related to power generation, odour reduction and the proper use of waste generated by production, as well as its destination in the soil.

It is generally observed that the environmental and social dimensions reflect weaknesses, and need improvements, especially the environmental dimension, as it presents negative externalities, in contrast to the economic-financial performance that stands out with positive externalities.

The findings demonstrate that the pork production chain can generate negative impacts on the environment. In this sense, it becomes relevant that the focal companies seek alternatives to minimize the impacts of pig production (Zanin & Bagatini, 2012; Kruger & Petri, 2019; Camargo et al., 2018; Kruger et al., 2022). It is recommended to use evaluation metrics to measure the economic, social, and environmental impacts of pig production (Kruger & Petri, 2019; Kruger et al., 2022; Kruger & Link, 2023).

5 CONCLUSIONS AND OPPORTUNITIES FOR FURTHER RESEARCH

The objective of the research was to identify the level of sustainability based on the analysis of the externalities of the pig farming activity, considering the criteria of the System for Management and Assessment of Sustainability in Pig Farming - Sigeass-

Web. The structured script allowed identifying the metrics and externality indicators of the social, environmental, and economic-financial dimensions.

The analysis makes it possible to identify that the economic-financial dimension presented remuneration for work and invested capital as positive externalities. The social performance indicators (social interaction, human capital and environmental practices) presented compliance levels according to the criteria observed in the Sigeass-Web model.

Regarding the environmental performance indicators, negative externalities were identified in the environmental assessment indicators of soil, water, air/greenhouse and energy, highlighting weaknesses in managers, as well as the need for improvements in the production process and in the management of natural resources. It is noteworthy that the analysis allows the evaluation of the property, highlighting the need for improvements in the production process, especially in the environmental sphere, aiming to reduce the negative impacts of pig production.

In this sense, the study corroborates discussions about the need to use indicators and assess sustainability, especially considering the economic and social importance of pig farming in the Brazilian context, for the generation of jobs and income in rural areas. Still, justifying that rural properties are an important link in the pig supply chain, it becomes necessary to manage resources, aiming to minimize the negative externalities of production.

In general, it can be noted that the results contribute to the assessment of the impacts of pig production, enabling advances and continuous improvements in the assessment of the sustainability performance of pig farming, including as an instrument to support the Sustainable Development Goals and the goals of the 2030 Agenda For future studies, it is recommended the application of the Sigeass-Web model to evaluate other study environments that develop pork production, as well as the continuity of the evaluation for the entity, as a way of improving and correcting negative externalities.

The findings demonstrate the importance of evaluating sustainability in production chains, aiming to correct the negative externalities of the productive process of rural activities, especially in the management of the supply chain of pig production, in order to contribute to the evaluation of performance in sustainability and improvement aspects identified as negative externalities.

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3. Development of theoretical propositions (theoretical work)		√	√
4. Theoretical foundation / Literature review		√	√
5. Definition of methodological procedures			√
6. Data collection	√	√	
7. Statistical analysis	√	√	√
8. Analysis and interpretation of data			√
9. Critical revision of the manuscript	√	√	√
10. Manuscript writing	√	√	√

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