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What are the externalities of pig production? A study in Danish and Brazilian farms

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Abstract

The study aims to analyze sustainability practices of pig farming in Brazil and Denmark based on the evidence of the activity's externalities. The Swine Sustainability Management and Assessment System (Sigeass) was used to analyze sustainability through 10 indicators and 60 assessment metrics. Data collection was carried out in four rural properties, two from each country, with full-cycle and independent production. The negative externalities refer mainly to the indicators of greenhouse gases emissions in the properties. The application of the system highlights the need for improvements concerning sustainability indicators to minimize the negative externalities of pig production. The application of swine sustainability management and assessment system highlights the need for improvements in relation to sustainability indicators, especially in the environmental dimension, according to the metrics evaluated, aiming to minimize the long-term impacts of pig production, as well as highlighting the relevance the insertion of continuous improvements in economic, social, and environmental aspects in favor of the sustainability.

Keywords: Sustainability; Sustainable Agriculture; Agribusiness; Swine

Quais são as externalidades da produção de suínos? Um estudo em propriedades rurais dinamarquesas e brasileiras

Resumo

O estudo tem como objetivo analisar práticas de sustentabilidade da produção de suínos no Brasil e na Dinamarca com base na evidência das externalidades da atividade. O sistema de gestão e avaliação da sustentabilidade suinícola foi utilizado para analisar a sustentabilidade por meio de 10 indicadores e 60 métricas de avaliação. A coleta de dados foi realizada em quatro propriedades rurais, duas de cada país, com ciclo completo e produção independente. As externalidades negativas referem-se principalmente aos indicadores de emissão de gases de efeito estufa nas propriedades. A aplicação do sistema evidencia a necessidade de melhorias nos indicadores de sustentabilidade para minimizar as externalidades negativas da suinocultura. A aplicação do sistema de gestão e avaliação da sustentabilidade da suinocultura evidencia a necessidade de melhorias em relação aos indicadores de sustentabilidade, principalmente na dimensão ambiental, de acordo com as métricas avaliadas, visando minimizar

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os impactos de longo prazo da suinocultura, bem como destacando a relevância da inserção de melhorias contínuas nos aspectos econômico, sociais e ambientais em prol da sustentabilidade.

Palavras-chave: Sustentabilidade; Agronegócios; Agricultura Sustentável; Suinocultura

1 Introduction

Pork occupies a prominent position in the ranking among the most produced and consumed globally, with China being the world's largest consumer (USDA, 2022). Brazil is one of the main producers and exporters of meat worldwide (ABPA, 2022). The pig production chain assumes several organizational forms that can be made up of independent producers, regional companies or complex vertically integrated production systems. Noteworthy, local characteristics, such as the size of farms, the supply of inputs needed for production, the profile of agroindustries, influence the viability of production systems. However, technological development, production, and market dynamics have favoured the migration from independent production to integrated production (GUIMARÃES et al*.,* 2017).

Economic development and environmental impacts related to agricultural production justify the analysis of activities in rural areas, especially in the context of the impacts generated by pig farming. The disclosure of externalities of the swine activity, considering the economic, social and environmental aspects, allows analising alternatives for adopting sustainable practices and implementing improvements, considering the particularity of each rural farm (KRUGER; PETRI, 2018).

Given the impacts caused by the swine activity, the concern about practices that make the activity sustainable emerges, and it is analyzed through indexes indicating environmental, social and economic dimensions. From this perspective, the need to generate measurable indexes within the production chains is evident, respecting the aspects of the current legislation (HIRAKURI et al., 2014; KARNIB, 2016). Discussions about sustainability corroborate concerns about aspects of success in rural areas.

The motivating factor of the research is the fact that pig production is practiced worldwide and by the high rates of pork consumption (MAPA, 2022). In this context, we opted for a comparative study between Brazil and Denmark. The Danish reference feature as a leader in quality, food safety, animal welfare, sustainable solutions due to cooperation between rural farmers, organizations and authorities, supported by comprehensive research and development program (LANDBRUG; FODEVARER, 2019). As a result, Denmark was the second-largest pork producer in the European Union in 2020, totaling of 23,935 million tons this year (USDA, 2020).

Although Denmark is a small country in territorial dimensions, Danish pork has been globally recognized and located as the most efficient and knowledge-based agricultural sectors (LANDBRUG; FODEVARER, 2019). Denmark has 38.37% of the total number of sows concerning Brazil and a much smaller number of farms (18.04%), and the number of pigs slaughtered by Denmark is 43.53% lower than in Brazil. Denmark's *per capita* consumption is 73.07% higher than Brazilian consumption, thus making the quantity exported by Denmark relevant, which exports only 24.32% less than Brazil. In contrast, the Brazilian production chain is positioned among the most advanced production chains in the world, with technologies and process controls to guarantee quality standards (MAPA, 2022). The presented data show the production potential of the two countries surveyed, justifying the comparative analysis between the production practices of the activity.

In this context, this research aims to analyze the sustainability practices of pig farming in Brazil and Denmark based on the evidence of the activity's externalities. The relevance of the discussion is supported by the economic importance in the generation of jobs and income in several regions; however, the activity presents several environmental risks that make it necessary to deepen the studies that have an optics focused on the sustainability of the activity developed.

This research seeks to contribute to the disclosure of the externalities of swine activity, considering the specificities of each rural establishment and analising the economic, social and environmental aspects, aiming to guarantee the sustainability of pig production in the long term. Furthermore, evaluating the indexes and implementing sustainability practices in the rural environment, it is possible to add improvements in the processes, considering the economic, social, and environmental.

The study differs concerning the specificities of swine activity and allows the analysis of negative externalities and improvements to minimize the impacts of swine production in rural areas. The applied model can contribute to other rural properties and serve as an example for new discussions about the externalities of rural production.

2 Theoretical background

Discussions about the need to seek sustainability as an alternative for the continuity of life on the planet are addressed by Elkington (2010), who defines sustainability as the triple bottom line that involves the economic, social, and environmental dimensions. Increasing

demands are made for organizations to pay attention to social and environmental models (GOMES et al., 2020).

Due to the environmental impacts of production, the development of sustainable production systems has been demanded (TAVARES et al., 2012; TAVARES et al., 2013). In the context of sustainability, problems emerge about the damage caused by the practices of swine activity. The waste generated by pig production polluted the environment, especially water, soil and air. Pig manure is one hundred times more polluting than urban sewage and causes environmental problems, such as air, groundwater and surface contamination), damages caused by such activity if there is no adequate destination.

The swine activity causes several environmental problems, considering the consumption of water an important environmental impact, either because of its use as a natural resource or because of the production and destination of associated waste (TAVARES et al., 2012; TAVARES et al., 2013). Externalities are considered positive or negative when they are derived from analyzes of an individual's productive structure or consumption relations (BAIARDI; MENEGATTI, 2011). The externality is considered negative when the action of one of the parties generates costs on the other, and it is considered positive when the action benefits both parties (MARQUES; COMUNE, 1997).

Negative externalities of the swine activity are considered to be air, groundwater and surface contamination, and this may occur through the inappropriate use of waste, such as the fact that rural producers dump part or all of the polluting material in natural rivers or lakes, as well as the excessive use of waste as fertilizers in the soil, thus compromising groundwater, causing the pollution of water wells intended for human consumption (WEYDMANN, 2005).

The positive externalities of the swine activity include the use of biodigesters for the treatment of waste, in addition to generating energy, it also generates the production of biofertilizers, thus reducing the environmental impact. The use of manure for organic fertilization is still positively considered, but there are few studies that show the adequate treatment process (WINTER et al., 2005).

With the increase in production and concentration of animals, it is necessary to look for alternatives to minimize the impacts generated by the destination of swine manure. For rural producers who invest in technologies, pig manure is a source of income, as it can be used as a biofertilizer in plantations and nutrients for the creation of fish in intercropped production systems (CASAGRANDE, 2003). Another alternative is to generate power using biodigesters, which can be used on the farm itself as well as the surplus sold (ABCS, 2016). Therefore, the

development of sustainable production systems has been demanded to reduce the environmental problems resulting from swine activity (TAVARES et al., 2012; TAVARES et al., 2013).

The consumption of water and other inputs has a significant environmental impact, either because of its expenditure as a natural resource or because of the intensity of the impact that results from the volume of waste generated in the pig production chain, mainly in the rearing and finishing phases. The problem of the generation of waste related to manure, which pollutes water, soil and air, was also discussed by Bartholomeu et al. (2007), who stated that the growth of pig production needs alternatives that guarantee the sustainability of natural resources and minimizes negative environmental impacts.

Given the economic dimension, externality arises when a productive structure or an individual's consumption affects others positively or negatively (BAIARDI; MENEGATTI, 2011). The negative externalities of swine activity involve contamination of air, groundwater and surface (WEYDMANN, 2005). Kruger (2017) highlights the concerns regarding the impacts of negative externalities of rural activities, emphasizing the need to seek improvements in favor of sustainable development.

In addition to the high index of development of pig production, the importance of the activity is evident, especially in the generation of jobs and income, making the study a motivating and vital source for the development or improvement of current practices that can make pig farming more sustainable in the economic, social, and environmental dimensions.

3 Material and methods

In order to highlight the positive and negative externalities of pig farming, Kruger (2017) established a set of metrics and indicators for assessing sustainability with the help of experts. Dalkey and Helmer (1963) point out that the Delphi method uses three characteristics basic: (i) repeated questioning of individuals/experts; (ii) avoids direct confrontation from the specialists, but does indirectly, controlled and anonymously through the method; (iii) allows you to know the opinions of experts.

Initial identification of sustainability indicators through selected literature; analysis and selection of measures, and indicators that contribute to the assessment of the economic, social, and environmental performance of pig production. Identifying legal and acceptable parameters for selected indicators, adjusting them in the form of benchmark metrics. The Delphi technique

is used at this stage, with the selection of experts (considering their prior knowledge of the research topic). Measures and indicators, as well as scales and reference levels will be evaluated by them using questionnaires. After analyzing the first round of application of the questionnaires, the indicators and performance metrics are adjusted, aggregating the opinions obtained, and then a new collection and evaluation of measures and indicators is carried out.

The second round of the Delphi technique with the experts will aggregate their perceptions and assessment for the validation of a set of performance measures and indicators for the assessment of the sustainability of swine production. The group of specialists in 3 categories stands out: (1) Technicians: professionals who work in the evaluation and performance of swine production practices, linked to entities and companies; (2) Managerial: professionals who know the context of production and work in the stages of analysis of the production process; (3) Scientific: professionals who know legal and regulatory aspects, especially regarding environmental assessment.

The research uses the Delphi technique to build an evaluation model. After reviewing the literature, applying interviews and questionnaires with experts, the Swine Sustainability Management and Assessment System (Sigeass) was developed by Kruger (2017). In this research, the Sigeass is applied based on a structured script in the form of a checklist*,* which identifies 10 indicators and 60 metrics that assess the economic, social, and environmental dimensions, enabling the disclosure of positive and negative externalities of pig farming. The central differential of the model is the evaluation by scales, which present the limit indicated as the minimum parameter of acceptability, and the identification of conditions that reflect realities that need improvement. According to metrics defined with specialists, these are the negative externalities, which are below the minimum of the parameters identified as regular. If the conditions represent practices or realities above the minimum or average conditions, these are positive externalities in the pig production (Table 1).

The research can be classified as a multi-case study, with data collection performed by applying the Sigeass checklist. It uses ordinal metrics (upper and lower levels), and employing cardinal scales allows identifying the compensation rates and the valuation of indicators. The application checklise application checklist makes it possible to compare the set of indicators between rural properties (KRUGER; PETRI, 2018). In the comparative analysis, it is possible to observe the positive and negative externalities of pig production, considering the specificities of each rural entity.

Table 1 - Criteria used to evaluate the performance indexes

Criteria for evaluating performance indexes	
Compensation fees (linear function) - CF	They indicate the general condition of service to the construct, considered 100% for cases that meet all indications / or metrics identified as superior measures. Compensation rates add up to 100% for each assessment aspect (the economic, social, and environmental).
Unit of measure - UM	Indicative unit of analysis (%, BRL [Brazilian Real], USD [dollar]), factors, meters, m^3).
Criteria for evaluating performance indexes	
Higher measures (ordinal) - HM	Higher level suggested as an ideal or favorable condition for the activity.
Lower measures (ordinal) - LM	Lowest suggested level, or minimum condition for the activity; below this condition, negative externalities are evident.
Higher score - HS	200 points.
Lower score - LS	-200 points.
Measure (cardinal) – ME	Identification of the condition of the rural entity based on its economic, social, and environmental conditions. Identified from the Sigeass structured roadmap and metrics.
Scoring by interval scale – SIS	It reflects the condition of the measures concerning the compensation rates of each set of indexes, showing the valuation of the positive or negative externalities of the activity.

Source: Adapted from Kruger (2017) and Kruger and Petri (2018).

This study comprises two pig farms in Denmark (A and B) and two others in Brazil (C and D). Table 2 displays the characteristics of the studied entities. We choose farms with comparable production characteristics. Through the application of the checklist, it was possible to characterize the sustainable practices of the farms participating in the investigation, showing the positive and negative externalities of pig farming. The choice of farms is justified with the adaptation of the model in analyzing the externalities of swine production, allowing the comparison of sustainability even among rural entities from different countries. In this respect, it highlights the contribution of the Sigeass as an assessment system for pig production practices.

Regarding the production phase of farming belonging to the study, the choice contemplated farms with complete cycle independent production, due to the production in Denmark is developed chiefly with these characteristics. In Brazil, independent production comprises about 40% of production (ABCS, 2016). Data collection was carried out with two pig farmers from Denmark and two pig farmers from Brazil, with pre-scheduled interviews with those responsible for the properties, online for the Danish and in person for the Brazilian.

Table 2 - Characteristics of the four farms with the main similarities and differences identified

Characteristics	**Farm A**	**Farm B**	**Farm C**	**Farm D**
Country - region	Denmark - Southern Denmark Region	Denmark - Southern Denmark Region	Brazil - West Region of the State of Santa Catarina	Brazil - West Region of the State of Santa Catarina
Characteristics	**Farm A**	**Farm B**	**Farm C**	**Farm D**
Country - region	Denmark - Southern Denmark Region	Denmark - Southern Denmark Region	Brazil - West Region of the State of Santa Catarina	Brazil - West Region of the State of Santa Catarina
Number of animals (total number of heads)	4,364	20,195	4,100	8,080
Number of matrices	285	900	450	550
Employees (family, third parties and managers)	3	12	6	19
Farm size (hectares)	196	760	46	80
Production system - production link	Complete cycle - independent			
Type of waste treatment system - capacity (m^3)	Forklift - 7,330	Forklift - 21,000	Forklift - 1,926	Forklift - 921
Average time of manure in the dumps (days)	270	300	120	120
Number of annual training/capacity hours	25	20	4	12
Number of animals				
Termination unit (TU)	2,006	12,000	1,800	4,400
Breeder	1,346	5,000	950	2,200
Complete cycle	4,364	20,195	4,100	8,080
Piglet production unit (PPU - 6kg)	727	2,295	900	930
The average number of matrices	285	900	450	550
Farm size (hectares)	196	760	46	80

Source: Authors, survey.

The choice of rural properties occurred initially due to the accessibility and availability of rural producers. Nevertheless, similar characteristics were observed regarding the management, size, and production system used, aiming to compare the indicators with the same conditions of exploitation of pig production. In this sense, in order not to limit it to two-sided cases, the

research expanded the analysis to two cases from each country to highlight the relevance of the findings and to identify particularities and characteristics, which might be very specific to each country or the rural entity analyzed, as a way to explore the validity of the model used.

Noteworthy, each pig farm was evaluated concerning each dimension, making it possible to analyze the positive, negative, and conforming externalities in the economic, social, and environmental dimensions. Among the three dimensions of sustainability, the general score and rates used for the general analysis and assessment of sustainability were observed and the metrics for the set of indexes.

The four farms present a complete cycle as a production system and do not have a productive link with any cooperative or private company, and their pig production is carried out independently. The owners or managers of the farms purchase inputs for the manufacture of the feed done on their properties, with the purchase of mineral additives to supplement according to each production stage.

4 Results

Table 3 shows the results of the analysis carried out regarding the environmental indexes of the surveyed farms, according to the evaluation of the Sigeass. It is possible to show that farm A presented as conformities concerning the environmental dimension: soil index, positively motivated by the physical-chemical analysis of the soil and the use of no-tillage practices.

For soil evaluation, phosphorus is one of the components that reflects in the evaluation of soil quality, its absorption capacity and/or contamination, although there are differences between soils, the suggested LCA-P is 40%, being the parameter critical environmental limit for the presence of phosphorus in the soil. However, the index was negatively influenced by the area of permanent preservation and legal reserve and the fact that the soil has the maximum level of phosphorus allowed by the model (40% IN 11/2015). Concerning the water index, there is positive control of the water consumed by the animals, the distance from the springs and water source facilities, the average number of animals per drinker; however, it scored negatively in the source of water used coming from an artificial source, and there is no reuse of water.

Table 3 - Evaluation of environmental indexes of pig production in the surveyed farms

Performance indexes		**CF**	**UM**	**HM**	**LM**	**ME Farm A**	**SIS Farm A**	**ME Farm B**	**SIS Farm B**	**ME Farm C**	**SIS Farm C**	**ME Farm D**	**SIS Farm D**
Evaluation elements		**Environmental performance indexes**											
Soil	Physical / Chemical analysis of the soil - 33%												
	Phosphorus environmental critical limit	50 %	%	20 %	40 %	40%	0	40%	0	40%	0	40%	0
	Phosphorus	50 %	mg/kg	60	110	110	0	100	20	100	20	100	20
	Soil conservation practices - 33%												
	No-tillage	50 %	%	90 %	70 %	100 %	150	0%	-200	100 %	150	0%	-200
	Crop rotation	50 %	factors	3	2	3	100	3	100	2	100	0	100
	Land occupation - 33%												
	Total area available / Number of animals housed	25 %	m³/ha/ year	30	50	1.02	245	0.84	200	0.30	200	0.11	200
	Total own area available / Waste production	25 %	m³/ha/ year	30	50	0.21	249	0.25	200	0.02	200	0.03	200
	% Permanent preservation area	25 %	meters	50	30	0.06 %	-150	0.07 %	-150	2.70 %	-150	15%	-149
	% Legal reserve	25 %	%	30 %	20 %	2.06 %	-179	6.64 %	-134	20%	0	33.30 %	133
Water	Origin of the source used for animal consumption - 50%												
	Natural sources	25 %	%	50 %	70 %	40%	150	0%	200	30%	200	80%	-50

(to be continued)

Performance indexes		CF	UM	HM	LM	ME Farm A	SIS Farm A	ME Farm B	SIS Farm B	ME Farm C	SIS Farm C	ME Farm D	SIS Farm D
Evaluation elements		**Environmental performance indexes**											
Water	Artificial fountains	25 %	%	40 %	20 %	50%	150	100 %	200	70%	200	20%	0
	Distance between springs or effluent installations	50 %	m	50	30	200	200	30	0	35	25	70	200
	Conscious use of water - 50%												
	Device to prevent water waste	50 %	yes no	3	1	2	50	2	50	2	50	3	100
	Water reuse	50 %	yes no	3	1	3	100	1	0	1	0	1	0
Air/Greenhouse effects	Greenhouse gas emissions, effluents and waste, by weight	50 %	m^3	60	40	0	-200	0	-200	0	-200	0	-200
	Air quality- 50%												
	Community satisfaction	50 %	%	10 %	30 %	10%	100	20%	50	5%	125	3%	135
	Windbreaks (air dispersion, if there is a natural barrier)	50 %	yes	2	0	2	100	2	100	2	100	2	100
Energy	Total energy use (in kwh) - 100%												
	Energy consumption	50 %	%	20 %	10 %	0%	-100	0%	-100	0%	-100	0%	-100

(to be continued)

Performance indexes		CF	UM	HM	LM	ME Farm A	SIS Farm A	ME Farm B	SIS Farm B	ME Farm C	SIS Farm C	ME Farm D	SIS Farm D
Evaluation elements		**Environmental performance indexes**											
Energy	Power generation	50 %	%	20 %	10 %	0%	-100	0%	-100	0%	-100	0%	-100
Environmental practices	Waste treatment - 20%												
	Process used	50 %	factors	3	1	1	0	1	0	1	0	1	0
	Activity waste destination	50 %	factors	4	1	1	0	1	0	1	0	1	0
	Disposal of solid waste	20 %	yes no	3	-	3	100	3	100	3	100	3	100
	Disposal of dead animals	20 %	yes no	3	-	3	100	3	100	1	33	1	33
	Environmental regularization - 20%												
	Compliance with laws and regulations	50 %	factors	3	1	3	100	3	100	2	50	2	50
	Notifications or fines received	50 %	factors	3	1	3	100	3	100	3	100	3	100
	Animal welfare - 20%												
	Area available per animal	25 %	meters	2.5	2.1	2.1	0	2.1	0	1.64	-115	1.64	-115
	Headquarters housing in collective pens	25 %	swine	4	2	3	50	3	50	3	50	3	50

(to be continued)

(conclusion)

Performance indexes		CF	UM	HM	LM	ME Farm A	SIS Farm A	ME Farm B	SIS Farm B	ME Farm C	SIS Farm C	ME Farm D	SIS Farm D
Evaluation elements		**Environmental performance indexes**											
Environmental practices	Floor type of premises	25 %	factors	3	1	3	100	3	100	3	100	2	50
	Number of animal by fountain	25 %	swine	10	12	7	200	5	200	10	100	10	100

Source: Authors, survey.

Related to the environmental practices of farm A, the housing of breeding stock in collective pens was positively verified and the fact that it had not received complaints or fines and the correct disposal of dead animals and waste. The negative externalities evidenced in farm A were related to the air greenhouse effect, motivated by the lack of natural barriers, and energy, as there is no installation of a system for waste treatment.

Conformities of the environmental dimension became evident in farm B: the soil index, positively motivated by the soil's physical-chemical analysis and crop rotation. However, the index was negatively influenced by the area of permanent preservation and legal reserve. Regarding the water index, the control of water consumed by the animals and the average amount of animals per drinker. However, the farm scored negatively on the water source, coming from an artificial source, such as the distance from springs and water source and no rainwater capture.

To identify the representativeness of the metrics for each of the indicators, the following criteria were considered: (i) the minimum aspects of acceptability or their break-even point, (ii) the ideal conditions or above the minimum acceptable, and (iii) those below minimum parameters or acceptability conditions. Such characteristics in relation to the indicators aim to allow the identification of criteria for the evaluation of aspects that need adjustments or improvements in the development of the swine activity. There is a consensus among specialists, for example, the availability of a dedicated area for the disposal of waste, although the possibility of using third-party areas for the disposal of waste from the activity is legally regulated, does not represent an adequate measure in relation to aspects environmental issues and represents a weakness when used in this way.

The concerns of specialists in the handling and destination of waste from the swine activity show the deficient aspects of environmental practices in the development of the swine activity. Considering that there are possibilities for swine exploitation and the proper disposal of waste using recommended techniques, as in the case of the use of biodigesters, which represent the environmentally less polluting alternative, by allowing the separation of gas, solid and liquid, and this liquid be reused as fertilizer in agricultural cultivation.

The use of other alternatives, such as manure and/or composting, also represent practices used, and as long as the fermentation time of these wastes is observed, they are also usual and allowed alternatives in the development of pig production. However, the use of biodigesters also represents the improvement of other aspects, such as the generation and reduction of energy consumption and the improvement of air quality, for the family and community.

In this sense, the distance between the facilities (pigs) and natural sources, especially when there is no relevant barrier, are aspects that raise concerns on the part of specialists, even in view of the relief that can make it easier for waste from the activity to reach natural sources (rivers, springs, streams, streams, etc.), impairing or contaminating water quality. It is not only the soil that can suffer from contamination from excess manure from frequent use, the proximity of facilities to natural sources is a factor that raises concern, especially because at the beginning of the commercial exploitation of swine, it was common for swine facilities to be very close, to allow the disposal of waste directly in them.

Environmental legislation recommends a minimum distance of 30 meters (in the case of sources up to 10 meters wide) between natural sources and facilities. In relation to the waste generated by the activity, there are two concerns: (i) with the packaging, jars and containers, which should be collected by its suppliers, but this is not always the case; In this regard, actions carried out by city halls, cooperatives, or collection points, etc., should be observed. Regarding the disposal of dead animals, the best recommendation would be the effective collection of these, by a specialized company for the disposal process, in these cases the producer would need to have space/conditions to freeze the dead animals, to later be delivered to such entity; incineration and composting are currently the most common techniques in the Brazilian context. Other concerns in relation to animal welfare, such as care with transport, accommodation, floor quality, water meter and number of drinking fountains per animal, represent aspects related to concerns with best practices in the development of pig farming, and although they are not yet

fully standardized in Brazil, represent improvements that must be implemented by international requirements.

Regarding the environmental practices of farm B, it was positively verified the housing of matrices in collective pens, as well as the fact of never having received complaints or fines and the correct disposal of dead animals and waste. The negative externalities evidenced were related to the air/greenhouse effect, motivated by the lack of natural barriers and the energy index, as there is no installation of a waste treatment system.

In farm C, conformities in the environmental index were evidenced, elements of soil assessment are positively motivated by carrying out the physical-chemical analysis of the soil, phosphorus limit, no-tillage practices with crop rotation. The areas of permanent preservation and legal reserve are evaluated positively. Negatively, the area of the dimension of land suitable for the use of waste was verified, being necessary the lease of neighbouring lands for the destination of the waste of the activity.

Soil conservation practices, such as no-tillage and crop rotation, reflect in the soil evaluation and in the phosphorus indices found in the evaluation of the composition and quality of the soil as a resource, considering that the waste from the swine activity is deposited or used as fertilizer in the cultivation of temporary crops or pastures. In this evaluation, no-tillage becomes a beneficial technique in soil conservation, and crop rotation is indicated as a best practice in soil use and conservation. In the set of land occupation evaluation, the relation of the total available area of the rural properties is observed, and its relation with the number of animals, considering the capacity of the soil to receive the amount of waste generated by the activity.

This criterion measures the availability of own area to allocate the waste generated, considering that the use of third-party land would be a counterpoint to the recommended criteria. Aspects of legalization in relation to permanent preservation areas and legal reserves, as in the example of legal reserves, indicate a minimum of 20% of the preservation area as legal reserves. In this case, 20% is the minimum acceptability parameter for environmental regulation, that is, not meeting this condition represents a negative externality. On the other hand, the disposition conditions of the areas above the indicated minimum (above 20%) represent adequate and favorable conditions in the context of the indicated evaluation.

There was a negative effect on not capturing or recycling water and the lack of effective control of water consumption. In terms of environmental practices, compliance with covered dung and the correct disposal of dead animals and waste was verified. Positively, having regular

environmental licensing and the rural environmental registry stands out, still the case of never having received fines, just a complaint from a neighbour regarding the odour of the waste used in the crops. As negative externalities of farm C, concerning the environmental dimension, there is a lack of the air/greenhouse effect indexes due to the lack of green barriers that allow odour control and energy because there is no biodigester system installed. The installation of a photovoltaic system was verified.

In farm D, the soil index became conformity of the environmental dimension, and the index was negatively influenced by the lack of no-tillage and crop rotation. Regarding the water index, the control of water consumed by the animals and the average number of animals per drinker comes from a natural source, and the rest is from an artificial source. However, there is no collection or recycling of water.

Concerning environmental practices, the housing of matrices in collective pens was positively verified and the fact that it had never received complaints or fines, the correct disposal of dead animals and waste, and the mandatory environmental regulation for the development of the activity. The negative externalities in farm D were related to air/greenhouse effect, motivated by the lack of natural barriers and the energy index, due to the lack of installation of a system for the waste treatment, such as a biodigester.

Table 4 presents the assessment of social performance indexes and measures for assessing sustainability. Regarding the social dimension of farm A, there was conformity in human capital, but the fact that there was no family member in carrying out the swine practice had a negative influence. The assessment elements related to social interaction were positively verified, such as concern for the quality of life of employees and the positive assessment of suppliers. However, participation in social groups was negatively assessed. Concerning external indexes, indexes from the state of Santa Catarina, Brazil, were used. In this sense, for Danish farms, it was not possible to identify specific external indicators.

Table 4 - Evaluation of the social indexes of the pig production of the analyzed farms

Performance indexes		**CF**	**UM**	**HM**	**LM**	**ME Farm A**	**SIS Farm A**	**ME Farm B**	**SIS Farm B**	**M Farm C**	**SIS Farm C**	**ME Farm D**	**SIS Farm D**
Evaluation elements		**Social performance indexes**											
Human capital	Satisfaction with rural areas	20%	note	9	7	8	50	8	50	8	50	9	100
	Work system - 20%												

(to be continued)

Performance indexes		CF	UM	HM	LM	ME Farm A	SIS Farm A	ME Farm B	SIS Farm B	ME Farm C	SIS Farm C	ME Farm D	SIS Farm D
Evaluation elements		**Social performance indexes**											
Human capital	Family labour	50%	number of people	4	2	1	-50	1	-50	2	0	1	-50
	Third parties/ employees	50%	yes/no	3	1	2	50	12	200	3	100	19	200
	Training and development of people - 20%												
	Technical capacity	50%	hours	20	10	25	150	20	100	4	-60	12	20
	Human capital development	50%	factors	3	1	3	100	3	100	3	100	3	100
	Family health	20%	yes no	3	1	3	100	3	100	3	100	3	100
	Family succession	20%	factors	3	1	2	50	2	50	3	100	3	100
Social interaction	Quality of life in the community	20%	groups	3	1	1	0	3	100	3	100	0	-50
	Social participation	20%	groups	3	1	1	0	2	50	2	50	1	0
	Social programs	20%	hours	15	5	25	200	20	150	4	-10	0	-50
	Perception of environmental impacts	20%	yes no	3	1	3	100	3	100	2	50	3	100
	Providers	20%	factors	3	1	3	100	3	100	3	100	3	100
External indexes	IDEB of the municipality	16.66 %	factors	8	5	7.3	77	7.3	77	7.3	77	7.3	77
	Sustainable municipal development index (Fecam)	16.66 %	index	0.8	0.5	0.59	31	0.59	31	0.629	43	0.629	43

(to be continued)

(conclusion)

Performance indexes		CF	UM	HM	LM	ME Farm A	SIS Farm A	ME Farm B	SIS Farm B	ME Farm C	SIS Farm C	ME Farm D	SIS Farm D
Evaluation elements		**Social performance indexes**											
External indexes	Sociocultural index (Fecam)	16.67 %	index	0.8	0.5	0.71	71	0.71	71	0.809	103	0.809	103
	Environmental index (Fecam)	16.67 %	index	0.8	0.5	0.48	-7	0.48	-7	0.380	-40	0.38	-40
	Economic index (Fecam)	16.67 %	index	0.8	0.5	0.53	9	0.53	9	0.628	43	0.628	43
	Institutional political index (Fecam)	16.67 %	index	0.8	0.5	0.65	51	0.65	51	0.697	66	0.697	66

Notes: External indicators in farms A and B are defined by the average of the state of Santa Catarina, considering that Fecam indicators (Fecam - Santa Catarina Federation of Municipalities) include only Santa Catarina municipalities. In this sense, for farms in Denmark, it was not possible to identify specific external indicators. The general average of the municipalities of Santa Catarina was used.
Source: Authors, survey.

It is observed that concerns about the relationship between consumption and production, which generate negative externalities over time, reflect on the scarcity of natural resources, global warming and intergenerational damage, and not all negative externalities can be compensated for. However, measuring and showing the impacts of economic activities on society or the environment are alternatives that contribute to some solutions, it was observed that legal responsibility, government regulation policies and public policies can be promoted based on these discussions and information. Over time, the concerns highlighted by previous studies regarding the impact of production and consumption relationships on the environment were observed. In this aspect, it is understood that allowing the evaluation of sustainable development through sustainability indicators become contributions towards the disclosure of negative externalities and guide the improvement processes in search of minimization of identified negative externalities.

In this sense, the contribution of the research is highlighted, allowing the assessment of the sustainability of swine production, based on a set of indicators and performance metrics contemplating the economic, social, and environmental aspects aimed at the development of this activity. Indications of the need to use fees to assess the degree of replacement of resources

to promote sustainable development are opportunities for further studies, including the need for international agreements and cooperation between countries, given the context of exports from swine production, the aspects that deserve attention. However, current conditions show the emerging need for specific public policies that can subsidize the installation of biodigesters or the charging of these investments by companies in the agroindustrial sector; in view of their corporate social responsibility, it is a necessary condition to minimize the negative externalities of pork production.

The model highlights the need to implement improvements in the development practices of swine production, aiming to effectively minimize the negative impacts of the activity, the negative externalities presented distance themselves from the sustainability of swine production, demonstrating the need for investments and targeted public policies to the adequacy of the processes of treatment and destination of swine waste, including as a factor of retention of families in rural areas.

The economic indicators (remuneration of labor and remuneration of invested capital), again indicate that there is adequate remuneration of the family's labor and the activity results allow the return of investments in time. These results reveal that the activity generates income and allows the return on invested capital; however, as well as that it is possible to add, from the investment in a biodigester, improvements in environmental and social indicators, which demonstrate that it is possible to generate a performance favorable to sustainability swine production, preventing negative externalities. In general, it shows that through the construct of indicators of swine production, it is possible to analyze the positive and negative externalities of its development, allowing for continuous improvements and seeking for the efficiency of rural production processes.

As a positive externality, farm B showed conformities in human capital for producer satisfaction concerning pig farming because there are outsourced and regularly registered employees, family succession in the management process, training and mandatory higher education courses. There is no removal of family members in the performance of activities. Labour remuneration was a positive externality; however, the element related to participation in social groups was negatively evaluated, motivating the non-conformity of the index.

Concerning the social dimension, in farm C, in the evaluation of human capital, a score was obtained from the producer related to satisfaction with the development of the activity, highlighting the family succession. The negative externality considers the fact that the outsourced employee does not have registration. The producer has technical courses and

graduation in the area of agricultural activity. Regarding external indexes, an index below the minimum limits accepted by the Sigeass is the environmental index with 0.380, showing that the municipality where the farm is installed still needs improvements in sustainable practices.

The positive externality in farm D was evidenced concerning the social dimension, conformities to human capital, for producer satisfaction concerning the pig activity. Because there are regularly registered employees, family succession in the management process, training and higher courses in agricultural technician, and veterinary medicine from the farm owner; however, participation in social groups was negatively evaluated, motivating the non-conformity of the index. Regarding external indexes, the lowest index was the same as that observed in farm C.

Table 5 shows the indexes for assessing pig production's economic performance in the surveyed farms. As a result of the applied methodology and compensation rates, a score can be added, and the *status quo* of each pig farm concerning each construct can be identified. In farm A, the return on invested capital was positive concerning the return on capital invested by hog housed, but there was a low profit and return on investment. As a positive externality, labour remuneration was evidenced, motivated by the different salaries concerning the amount paid in other properties. In the case of farm B, the return on invested capital concerning the return on capital invested by housed pigs was shown as a negative externality, but compliance with profit and return on investment was achieved.

As a positive externality, in farm C, the remuneration of labour, the return on investment and the profit from the activity were verified, but the return on investment per pig housed was negative. Positively, in farm D, the remuneration of the invested capital was evidenced, which was negative concerning the remuneration of the capital invested by the housed pig, and it was obtained conformity concerning the profit and the return on investment.

Table 5 - Evaluation of the economic indexes of pig production in the analyzed farms

Performance indexes		**F**	**M**	**M**	**M**	**E Farm A**	**IS Farm A**	**E Farm B**	**IS Farm B**	**E Farm C**	**IS Farm C**	**E Farm D**	**IS Farm D**
Evaluation elements		**Economic and financial performance indexes**											
Compensation of labour	Compensation of labour	00%	RL	.50	.00	5.7	00	.28	00	.72	00	.48	8
Remuneration of invested capital	Remuneration of invested capital - 100%												
	Return on investment per hog housed	3.33%	RL	.8 MW*	.20 MW*	.72	130	.79	148	.24	00	.32	00
Performance indexes		**F**	**M**	**M**	**M**	**E Farm A**	**IS Farm A**	**E Farm B**	**IS Farm B**	**E Farm C**	**IS Farm C**	**E Farm D**	**IS Farm D**
Evaluation elements		**Economic and financial performance indexes**											
Remuneration of invested capital	Net profit from the activity	3.33%	RL	5%	5%	4.36%	6	3.33%	3	8.72%	7	4.60%	4
	Return on investment	3.33%	ear		2	8.3	200	1.3	8	.50	00	.4	00

Notes: *MW = Minimum Wage; 954 BRL (2018 base).
Source: Authors, survey.

Table 6 presents the scores and rates for each construct, with higher metrics (positive externalities) and lower metrics (negative externalities) to assess the pig farms' economic, social, and environmental performance. The score of economic, social, and environmental performance indexes is verified. Firstly, the direct score is presented and the rates among the total indexes, with each farm being represented by 25% for each set of indexes. The *status quo* of the performance of the indexes was obtained, identifying the highest overall performance (farm C) and the lowest overall performance (farm A).

Table 6 - *Status quo* of sustainability indicators

Performance indexes		**Punctuation**	**Fees**	**HM**	**LM**	***Status quo* Farm A**	***Status quo* Farm B**	***Status quo* Farm C**	***Status quo* Farm D**
Environmental	Ground	20%	6. 67%	100	0	55	-4	66	19
	Water	20%	6.67%	100	0	125	63	69	69
	Air/greenhouse effect	20%	6.67%	100	0	-50	-63	-44	-41
Performance indexes		**Punctuation**	**Fees**	**HM**	**LM**	***Status quo* Farm A**	***Status quo* Farm B**	***Status quo* Farm C**	***Status quo* Farm D**
Environmental	Energy	20%	6.67%	100	0	-100	-100	-100	-100
	Environmental practices	20%	6.67%	100	0	78	78	48	46
Social	Human capital	33%	11.11%	100	0	65	75	64	87
	Social interaction	33%	11.11%	100	0	80	100	58	20
	External indexes	33%	11.11%	100	0	39	39	49	49
Economic	Compensation of labour	50%	16.66%	100	0	200	200	200	98
	Remuneration of invested capital	50%	16.66%	100	0	-112	-16	146	132
Total		**300%**	**100%**	**100**	**0**	**42**	**53**	**79**	**55**

Source: Authors, survey.

The results of the Sigeass show that there are opportunities for improvement in the three dimensions of sustainability assessed on rural farms.

5 Discussion

Based on Table 2, the main differences between Danish and Brazilian farms are discussed. Farm B is the largest farm participating in the survey in relation to the number of matrices and the size of the rural property. The farms with a larger number of headquarters (B and D) have the most employees, including managers; however, farm B has a larger area than farm D, which has the largest number of employees. These data show that the investments made in technology and infrastructure in farm B enable activities to be carried out by a smaller number of employees. Such a situation may be associated with Denmark's relevance in the international agribusiness scenario because Danish agriculture focuses on investments in knowledge and qualification of the workforce.

Negative environmental externalities can be minimized through adequate waste treatment techniques, such as the use of biodigesters. When the waste generated is in excess, and all materials produced are not reused or recycled, as in the case of the relationship between the available area and the amount of waste generated, the environment is affected by excess waste (it can compromise water resources, air quality, generate greenhouse gases). Negative externalities are related to pollution and contamination of natural resources (Cechin and Veiga, 2010).

Aspects related to the control and measurement of externalities must consider the balance of the relationship between production, consumption and environment (Bithas, 2011). In this sense, the importance of evaluating and highlighting production practices is perceived, in order to enable the correction of negative externalities of production processes, observing the economic, social, and environmental context, through sustainability indicators, allowing the evaluation guides adjustments and improvements that minimize the negative externalities identified.

The theoretical basis and previous studies demonstrate the importance of building indicators and metrics to assess sustainability. According to Santiago-Brown et al. (2015), the triple bottom line approach is needed to assess long-term development, wealth and social well-being, as economic and social factors are as essential components as environmental aspects in sustainability assessments in the countryside. In this sense, the relevance of the proposed model is highlighted as a mechanism for evaluating the sustainability of swine production.

Farm C has 46.1 hectares of total land area, but the waste is deposited on 21.4 hectares of its own and another 109 hectares of neighbouring areas that the producer has a contract for

the deposit of waste, as authorized by law; however, this indicates a weakness related to the lack of own area, a detrimental factor to sustainability. This fact was also evidenced by Kruger (2017), the majority of pig properties are small concerning the number of hectares of land, thus not having enough area for the final destination of the waste.

The farms A and B have a greater capacity than farms C and D due to the need for waste in Denmark to stay for an average time of 270 to 300 days in the fermentation process and, after this period, they are used in fertilizing crops. On the other hand, the farms in Brazil are smaller, as the waste is only for 120 days and, after that, they are used as fertilizer in crops. Kruger (2017) show that properties that do not have a biodigester system for waste treatment use the composting system, and later the waste is deposited in crops as a form of fertilizer for plantations.

Based on the difference of days of manure in the dung and their capacities, the Danish legislation elaborated in 1987 requires storage capacity for 12 months (Palhares, 2009). It can consider the fact that Denmark stands out in environmentally efficient production. Although in the past 25 years, pig production in Denmark has increased, at the same time, it has reduced environmental impacts. Two pigs for slaughter are currently produced with the same environmental impact as a pig produced in 1985 (Landbrug and Fodevarer, 2019).

Positive aspects of Denmark stand out concerning Brazil, mainly in the environmental dimension, with emphasis on the fact that the residues are lodged for an average period of 270 to 300 days in the manure and on the fact that the residues are placed in the soil 2 cm below the surface, showing opportunities for improvement for Brazil concerning the environmental dimension.

When analyzing the aspects that involve the social dimension, the average training time of 20 to 25 hours that managers and employees in Denmark receive annually can be highlighted. This shows the difference in the reality of the Brazilian case. This essential for the efficient use of new technologies implemented in the farms' process. In contrast, Brazil’s strong point is its active participation in labour unions, cooperatives and associations.

Regarding the economic dimension, farms C and D show a faster return on investment than farms in Denmark. On the other hand, Danish farms invest in technologies that have high costs, showing that the country has a concern for sustainability economic and financial situation in the long run (not only in the quick return), as Brazilian farms. In general, the importance of sustainability analysis is verified for the continuous improvement of the management and

productivity process, benefiting the rural farm in minimizing social, environmental, and economic-financial impacts.

6 Conclusions

Using the Sigeass, it was possible to characterize the environmental, social, and economic-financial practices of pig production in farms in Denmark and Brazil, as well as to make it possible to measure from a set of indexes and metrics of sustainable practices in pig production in both countries, highlighting externalities of the activity.

The analysis made it possible to identify the production weaknesses in each farm studied. Some characteristics of production in Denmark, such as high wages, total days that the waste is in the dung, total hours of training, amount of available area, training of managers, characteristics of the facilities, presented higher scores, the maximum measure of the Sigeass model, considering that the model was created from the Brazilian reality, and indicates the maximum score of 200 points per metric.

Given the economic and social importance that swine farming presents, it is necessary to develop measures that maximize the positive results of the activity and minimize the negative impacts resulting from the activity. Thus, the development of the pig industry can assist in meeting the goals of sustainable development.

Considering this study's limitations, it is impossible to generalize the results since only two pig farms from each country were analyzed. However, it is possible to contribute with practices adopted by other countries to guarantee pig farming with the best sustainability practices, still allowing for an analysis of negative externalities that need attention and implement continuous improvements. Furthermore, the analysis made it possible to evaluate the sustainability performance of pig production, considering the specificities of the analyzed rural farms.

The relevance of using sustainability indexes such as those of the Sigeass model is highlighted, aiming to contribute to improvements in the development of rural activities, especially for the implementation of improvements related to the production practices of the swine farming, observing the social, environmental and economic-financial contexts of the activity in order to minimize the negative externalities of production.

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