

LIFE CYCLE ASSESSMENT OF PIG PRODUCTION: A CASE STUDY

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Abstract - Pig farming plays a crucial socioeconomic role in the European Union (EU), with Germany, France, and Spain leading pork production. In Portugal, pig farming is vital for regional development and national economy. To ensure future sustainability, it is essential to identify the pig production activities that have the most significant environmental impacts. This study carried out a Life Cycle Assessment (cradle-to-gate) of pig production using a conventional system in central Portugal to identify the phases with the greatest environmental impact. LCA followed the ISO 14040/14044 standards, covering the production cycle, using 1 kg of live pig weight as a functional unit. The analyzed scenario encompasses everything from the production and growth of piglets to the pig fattening phase, including the formulation of specific feed for each stage of development, transport of inputs, use of diesel to generate electricity in the facilities, and management of pig manure. The results highlight feed production and piglet management as the most important steps. The study highlights the importance of sustainable practices in order to mitigate environmental issues such as human carcinogenic toxicity and the ecotoxicity of freshwater and marine water, emphasizing the need for improved strategies in pig farming.

Keywords - Pig Farming; Life Cycle Assessment; LCA; Environmental Impacts

I. INTRODUCTION

Pig farming is a socioeconomic activity of great importance in the European Union (EU), and this region is one of the largest exporters of pork in the world. Countries such as Germany, France, and Spain are major producers, producing approximately half of the total pork produced in the EU and 21.8% of global pork production in 2019 [1].

In Portugal, animal production contributes approximately 40-50% of the overall agricultural production, and pig farming accounts for approximately 19-20% of the total meat production in the country [2]. This sector not only drives the development of the areas where it is present but is crucial for balancing the Portuguese trade balance and the population's food supply.

However, pig production chains face challenges in terms of sustainable management, animal welfare, and technological advances [3]. The entire livestock production system can generate environmental burdens, from feed production to waste disposal, which can have a substantial impact on water, air, soil quality, biodiversity, and global climate [4].

Life cycle assessment (LCA) is a methodology that aims to evaluate the environmental impact of a product throughout its entire useful life, from raw material extraction to disposal and recycling. The process encompasses multiple steps, such as

manufacturing, transportation, installation, use, maintenance, and end-of-life to provide a comprehensive analysis of a product's sustainability performance [6].

LCA methodology is essential for gaining an in-depth understanding of the entire lifecycle of a product or activity, going beyond the manufacturing stage to encompass raw material extraction, distribution, product use, and waste management. By considering all these steps, LCA adopts a “cradle to grave” approach, allowing for a meticulous assessment of the environmental impacts of industrial systems [7].

The current literature demonstrates that feed production is one of the stages with the most significant environmental impacts. In general, the production of food ingredients, such as corn and soy flour, has substantial impacts on global warming, acidification, and eutrophication, leading to high environmental burdens [5].

It is essential to identify and quantify the environmental impacts of each stage of the pig production system with the aim of introducing sustainable practices that help mitigate the environmental impacts commonly observed in this production system. Therefore, this study aimed to develop a Life Cycle Assessment (LCA) in a conventional beef pig production system to analyze the environmental impacts present in this production system and identify the influence of each production

stage on these impacts.

II. MATERIALS AND METHODS

A. Case study

The case study was based on the production system of a company specializing in fattening pigs for slaughter, with an operational unit located in Tentúgal, Coimbra (center of Portugal). This property is not connected to the electricity grid, and therefore requires the use of a diesel generator to meet its energy needs. The water for this property was well supplied.

The fattening pigs for slaughter were organized into two production stages. In the first phase, carried out on another property, the sows are bred and inseminated, going through a gestational period that culminates in birth. Newborn piglets were weaned and raised until they reached a target weight of approximately 19 kg when they were transferred to Tentúgal. In the second phase, the fattening phase, pigs are fed until they reach a live weight of approximately 115 kg and are then sent for slaughter.

Every three months, the areas where the pigs are kept are washed and the resulting slurry is sent to a lagoon and then used in agriculture, in collaboration with local farmers.

B. Life Cycle Assessment (LCA)

Environmental impact assessment was conducted using the LCA framework in accordance with the ISO 14040/14044 guidelines.

Life cycle assessment entails several critical components that are necessary for assessing the environmental consequences of a product throughout its life cycle. These components include selecting a functional unit, defining study objectives, developing an inventory, evaluating environmental impacts, and interpreting results for informed decision-making.

Aim and Scope of the Study

The main objective of the LCA was to evaluate the environmental impacts associated with the production of pigs for slaughter on a pig farm in Central Portugal. Other objectives of the study were to identify the main critical points throughout the life cycle and propose improvements to reduce environmental impacts.

Functional unit (FU)

The functional unit was assumed to be 1 kg of live pigs that left the farm.

System boundaries

The scope of this study covered all processes related to pig farming and pig slurry management (i.e., from cradle-to-gate). The pig slurry was treated as a residue, as shown in Fig. 1.

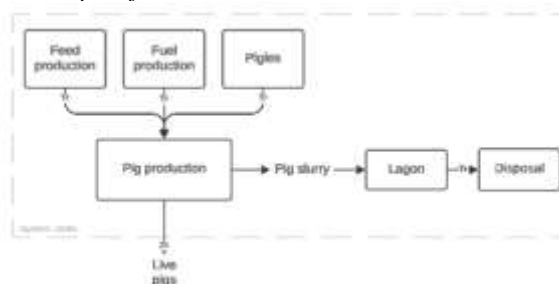


Fig. 1. System limit for pig production

System boundaries cover all stages of the pig production life cycle, including the following:

- Feed production with formulation, mixing and addition of nutritional additives;
- Fuel production and transport of refined diesel oil to distribution points;
- Piglets' production (3-month-old);
- Pig production (farming activities);
- Pig slurry management (pit storage > 1 month) at farm. Emissions included are: CH₄ from enteric fermentation and from manure, N₂O (direct and indirect), NH₃, NO_x, PM, and NMVOC emissions from manure.

Life Cycle Inventory (LCI)

The pig production inventory data for 2023 is presented in Table 1. With these data, the LCI was built with the help of the SimaPro software 9.6.0.1.

Item	Unit	Quantity
Inputs		
Feed	ton/year	2126
Water	m ³ /year	5851
Diesel	l/year	5700
Piglets	ton/year	167
Transport (piglets and feed)	t.km	173266
Outputs		
Pigs	ton/year	835
Slurry (residue)	ton/year	4908
Atmospheric emissions		
Ammonia (NH ₃)	kg/year	8931
Dinitrogen monoxide (N ₂ O) - direct	kg/year	67
Dinitrogen monoxide (N ₂ O) - Indirect	kg/year	109
Methane, biogenic	kg/year	2021
Methane, biogenic	kg/year	27484
NMVOC, non-methane volatile organic compounds	kg/year	706
Nitrogen oxides (NO _x)	kg/year	181
Particulates < 10 um	kg/year	369
Particulates < 2.5 um	kg/year	16
Particulates SPM	kg/year	2772

Table 1. Inventory data of the pig production system.

Data on piglets and feed production were adapted to Portugal from the Agri-footprint database processes "Piglet, at farm {ES} Economic, U" and "Swine

compound feed, at processing {ES} Economic, U”, respectively, available in SimaPro software 9.6.0.1.

C. Life Cycle Impact Assessment (LCIA)

Similar to LCI, LCIA was implemented using SimaPro software 9.6.0.1. The ReCiPe 2016 Midpoint (H) V1.09 / World (2010) H method was used to quantify the environmental impact at the midpoint (MP) levels from a hierarchical perspective to obtain an environmental profile, such as the normalized environmental profile.

Normalization is a fundamental step for comparing environmental impacts in different categories, allowing the identification of areas of greater or lesser significance. The unit of measurement used in this process is Equivalent Inhabitants (Hab.eq.) serves to quantify the potential impact of a specific process in relation to the average impact of a European citizen.

III. RESULTS AND DISCUSSION

Life Cycle Assessment (LCA) applied to beef pig production revealed a broad analysis of the individual

contributions of each phase of the production process to global environmental impacts. The study covered everything from the production and growth of piglets to the pig fattening phase, including the formulation of specific feed for each stage of development, transport of inputs, use of diesel to generate electricity in the facilities, and pig manure management. Each of these steps was carefully analyzed to understand its role in different categories of environmental impacts, such as greenhouse gas emissions, acidification, eutrophication, and toxicity. This approach allows for a detailed understanding of the complexity of the pig farming production chain, highlighting the most critical areas that contribute to the total environmental footprint.

The graph shown in Fig. 2 provides a detailed analysis of the environmental impacts of several categories of pig production based on LCA parameters. The swine compound feed process stands out as the most responsible for the impacts, contributing between 50% and more than 80% in practically all categories analyzed.

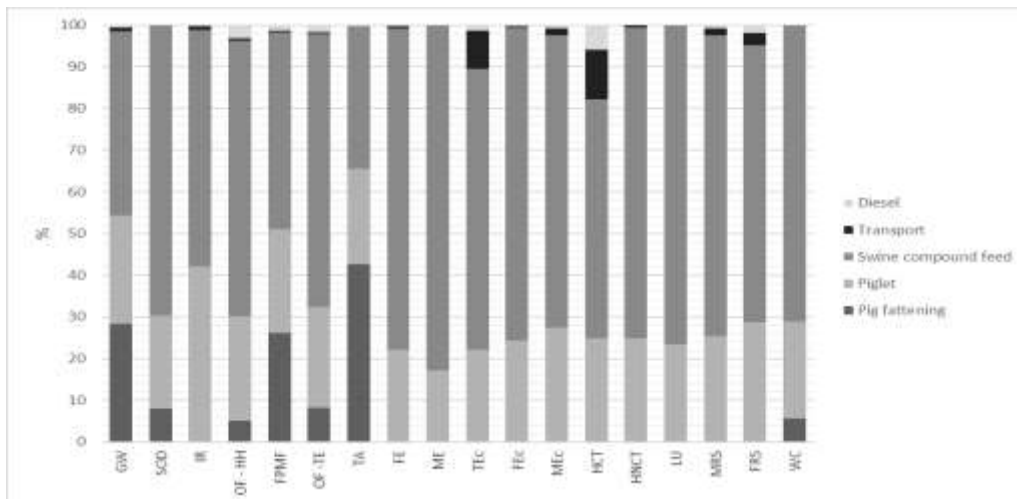


Fig. 2. Environmental profile (characterization) of the FU using the ReCiPe 2016 Midpoint method. – Acronym: GW: Global Warming; SOD: Stratospheric Ozone Depletion; IR: Ionizing Radiation; OF - HH: Ozone Formation - Human Health; FPMF: Fine Particulate Matter Formation; OF - TE: Ozone Formation - Terrestrial Ecosystems; TA: Terrestrial Acidification; FE: Freshwater Eutrophication; ME: Marine Eutrophication. TEc: Terrestrial Ecotoxicity; FEC: Freshwater Ecotoxicity; MEc: Marine ecotoxicity; HCT: Human Carcinogenic Toxicity; HNCT: Human Non-Carcinogenic Toxicity; LU: Land Use; MRS: Mineral Resource Scarcity; FRS: Fossil Resource Scarcity; WC: Water Consumption.

These results highlight the crucial role of food in determining the environmental impacts throughout the life cycle of pig production. Studies on pig production corroborate these findings, indicating that feed production generally accounts for 56% to 95% of the environmental impacts in pig production systems, with corn being the main contributor [8].

In the Global Warming (GW) category, pig feeding was responsible for approximately 45% of the impacts, with smaller contributions from pig fattening and piglet production. This reflects the significant influence of feed production on greenhouse gas emissions. According to Yang et al. [9], feed production is one of the main factors contributing to

the high carbon footprint of swine production, which can reach 6.75 kg CO₂-eq per kg live weight. The high corn content in feed is directly related to high greenhouse gas emissions, and diets with a high corn content can generate impacts of up to 645 kg CO₂-eq per ton of food [10].

In the Terrestrial Acidification (TA) category, swine compound feed presents the lowest relative contribution, corresponding to approximately 35% of the total impact. However, the pig fattening phase makes a significantly greater contribution, being responsible for approximately 45% of the impacts in this category. This trend indicates that the fattening phase is mainly responsible for soil acidification,

largely because of the high excretion of nutrients, such as nitrogen and phosphorus, and the nutritional composition of the feed used. Pig fattening is particularly critical because it involves high feed intake by pigs, resulting in large manure production, which is one of the main factors related to soil acidification. Excreted nutrients, mainly nitrogen and phosphorus, are the biggest contributors to this phenomenon [10].

In addition to terrestrial acidification, the fattening phase plays a relevant role in other environmental impact categories. In the case of Global Warming (GW), its contribution is 28%, while in Fine Particulate Matter Formation (FPMP), the share reaches 25%. This demonstrates that this stage of the pig production cycle is a critical phase not only for acidification but also for the emission of greenhouse gases and the generation of fine particles, aggravating several aspects of environmental degradation.

The piglet rearing phase also plays a significant role in several environmental impact categories, although it is never the main contributor. Its participation varies between 20% and 30% in several categories, except for two: in the Ionizing Radiation (IR) category, where its contribution reaches an expressive value of 42%, and in Marine Eutrophication (ME), where it presents the lowest participation, at 17%. Piglet farming and breeding sow management have substantial environmental impacts, including greenhouse gas emissions, high water and energy consumption, and problems associated with waste management. The feeding of breeding sows contributes significantly to emissions, and the manure generated by this phase of the cycle is an important factor in both soil acidification and eutrophication of aquatic ecosystems. Therefore, improvements in the sustainable management of pig production may represent a significant opportunity to mitigate these adverse environmental impacts.

Other stages of the production cycle, such as transport and diesel consumption, make smaller contributions to the environmental impacts, although they cannot be disregarded. Transport, for example, is particularly relevant in the categories of Human Carcinogenic Toxicity (HCT) (12 %) and Terrestrial Ecotoxicity (TEc) (9 %). Diesel consumption stands out exclusively in the Human Carcinogenic Toxicity category, contributing 6% of the total impact. These data highlight that, despite representing a smaller portion of the total environmental impacts, activities related to transportation and consumption of fossil fuels still play a relevant role in some specific impact categories.

In short, the swine compound feed phase emerged as the main contributor to the environmental impacts. However, other stages of the production cycle, including the creation of piglets, together with the management of matrices and pig fattening, also have considerable impacts, highlighting the need for process improvements.

When analyzing the normalized environmental profile illustrated in Fig. 3, it is observed that the category with the greatest environmental impact is Freshwater Ecotoxicity (FEc), which presents an approximate value of 0.012 Hab.eq. The categories of Human Carcinogenic Toxicity (HCT) and Marine Ecotoxicity (MEc) occupied second and third positions, with values of 0.006 Hab.eq. and 0.003 Hab. eq., respectively.

These data highlight the relevance of swine compound feed production stages and piglet breeding in contributing to these impacts. These stages stand out because of the high consumption of natural resources, significant pollutant emissions, and production of excretions, which can result in soil acidification and eutrophication of water bodies.

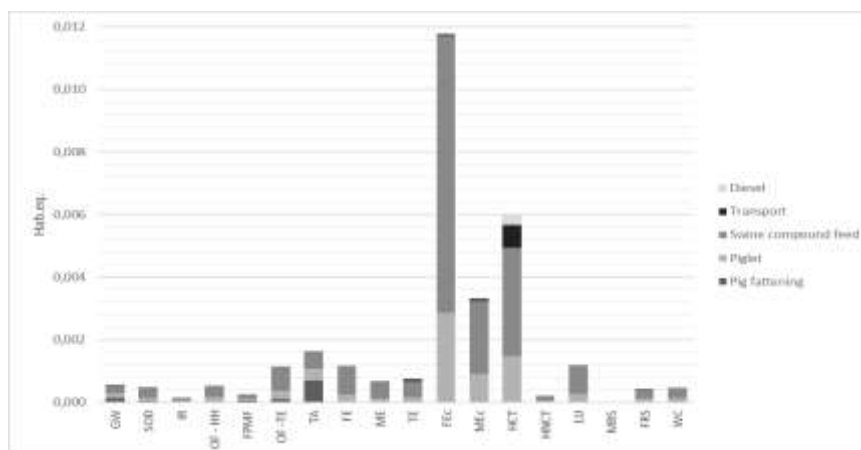


Fig. 3 Environmental profile (Normalization) of the FU using the ReCiPe 2016 Midpoint method. – Acronym: GW: Global Warming; SOD: Stratospheric Ozone Depletion; IR: Ionizing Radiation; OF - HH: Ozone Formation - Human Health; FPMP: Fine Particulate Matter Formation; OF - TE: Ozone Formation - Terrestrial Ecosystems; TA: Terrestrial Acidification; FE: Freshwater Eutrophication; ME: Marine Eutrophication. TEc: Terrestrial Ecotoxicity; FEc: Freshwater Ecotoxicity; MEc: Marine ecotoxicity; HCT: Human Carcinogenic Toxicity; HNCT: Human Non-Carcinogenic Toxicity; LU: Land Use; MRS: Mineral Resource Scarcity; FRS: Fossil Resource Scarcity; WC: Water Consumption.

In contrast, the other impact categories presented relatively low values, all below 0.002 Hab.eq., indicating lower environmental relevance. This analysis is crucial for direct mitigation efforts in areas that have the greatest environmental impact, thus promoting more sustainable production. Furthermore, it provides valuable information for formulating strategic decisions aimed at reducing the environmental effects associated with pork production, thereby contributing to the development of more responsible and efficient practices in the sector.

IV. CONCLUSION

An Life Cycle Assessment examining the environmental effects of a particular swine operation in Portugal underscores the intricacies and obstacles confronting this crucial industry for both national and regional economies. The study outcomes revealed that the primary sources of environmental impact are the feed production phases and piglet rearing, particularly in areas such as freshwater and marine water ecotoxicity, as well as human carcinogenic toxicity. These discoveries emphasize the necessity of implementing sustainable management practices and technological advancements aimed at not only decreasing greenhouse gas emissions but also enhancing the utilization of natural resources. Efforts to mitigate these impacts should concentrate on feed formulation, considering the substantial environmental footprint linked to ingredients such as corn, and on sustainable practices in piglet raising and breeding sow maintenance. By prioritizing these measures, it is possible to contribute to more environmentally friendly pig production, harmonizing economic growth with environmental conservation. Consequently, this study offers valuable guidance for

the swine industry by promoting strategic choices aimed at lessening environmental impacts and ensuring the long-term sustainability of the sector.

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