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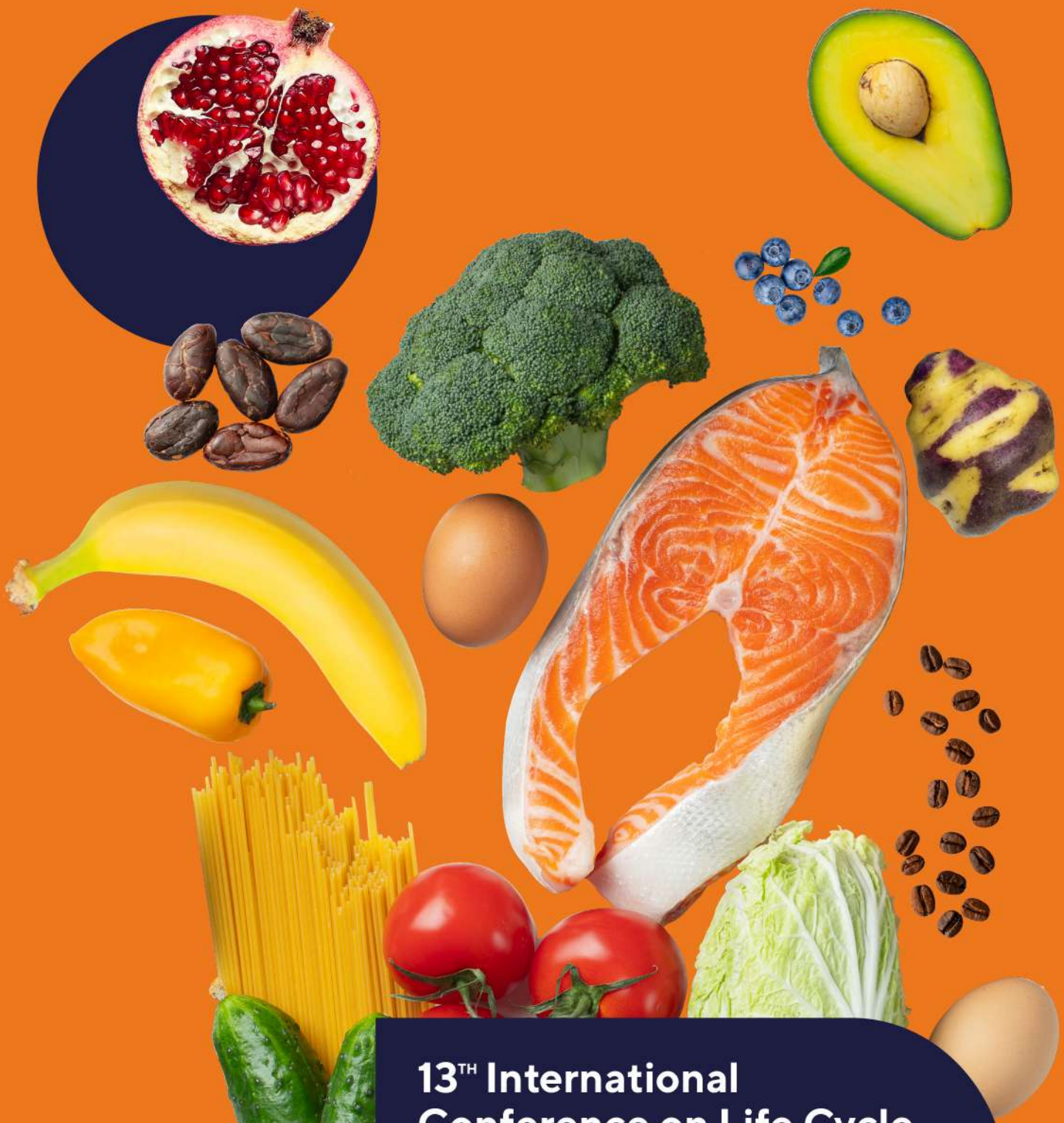

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Pig Farming Under a Life Cycle Thinking Lens: The First Combined Environmental, Economic and Social Life Cycle Analysis

Michele Costantini[1*], Marcella Guarino[1], Jacopo Bacenetti[1]

[1] *Department of Environmental Science and Policy, University of Milan, Milan, Italy*

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**Corresponding author: michele.costantini@unimi.it*

1. Introduction

The pig production sector has a significant socio-economic weight in the European Union. The EU-27 host a yearly average population of 150 million pigs, which alone accounts for nearly half of total EU meat production. Pork is the most consumed meat in the EU in general and in many member states individually, including Italy, where the supply chain specializes in the breeding of the so-called heavy pig, intended to produce dry-cured hams.
Increasing attention is being paid to the sustainability of food systems both by national and EU policies and by consumers themselves. Animal production chains are particularly under observation due to the environmental problems associated with them. Many environmental studies focused on pig production chains, extensively with the life cycle assessment approach (McAuliffe et al., 2016), in some cases also combined with economic considerations (Pexas et al., 2020). On the other hand, studies that have considered social aspects of the supply chain have been more limited (e.g. Zira et al., 2020).
The aim of this study was to approach the sustainability of the pig farming production system from all three points of view for the first time. This has the dual objective of testing the methodological combination of the three sustainability analyses and highlighting any similarities, shared hotspots or even trade-offs of the different layers and having a more complete view of the supply chain impact. A case study was conducted in Northern Italy (Lombardy region), which concentrates a high share of the country's intensive pig farming, by means of primary data collected from closed-cycle pig rearing farms.
Starting from the results, an alternative scenario was explored in which the introduction of an emerging mitigation technique was tested in order to explore its possible influence on the three layers of sustainability. This is represented by an end-of-pipe air treating technology, currently not widespread in the sector in Italy, which concerns air scrubbing to reduce particularly ammonia (NH_3), and even particulate emissions, from the housing phase (Santonja et al., 2017). The environmental, economic and social consequences associated with NH_3 emissions are, in fact, currently one of the main issues related to pig farming, especially if intensive and located in populous areas such as the Po Valley.
The construction and maintenance of air scrubbers involves the consumption of acid, energy, and materials such as stainless steel, in addition to an increase in the workload for its management and that of a liquid nitrogen-rich effluent that is co-produced by its operation; but at the same time it achieves very high NH_3 emission reduction efficiencies (up to 99%, but in operating conditions it is reasonable to consider efficiencies around 70%), and if it is used with air that recirculates inside the stables it also improves the environment and therefore in theory of the welfare of animals and operators. This study therefore also aims to evaluate, thanks to the alternative scenario, all the pros and cons of this mitigation strategy with a view of its impact as complete as possible.

2. Methods

Questionnaires were set up relating to production, technical, economic performance and social and environmental conditions that could best characterize the farms involved; and compiled by means of field surveys and meetings especially with farmers, and with other actors in the supply chain (e.g., agricultural technicians, agricultural services provider companies, veterinarians). As for the alternative scenario, the primary data collected by the farmers were integrated with data deriving from various experimental campaigns held during the Life-MEGA Project, supported by the EU, aimed precisely at measuring environmental, economic and social consequences from implementation of air scrubber prototypes in Italian pig farms.
The environmental impact was analyzed with the life cycle assessment in a cradle-to-farm gate approach with 1 kg of live weight (LW) produced, ready to be sold to the slaughterhouse, as functional unit. This is in line with similar studies carried out in the literature, as well as consistent with the adopted system boundaries. The inventory data collected directly in the farms were integrated with secondary data related to estimates of emissions from animals (enteric and manure management), while background data were retrieved from the established Ecoinvent® database (Wernet et al., 2016). The final inventory was characterized with a midpoint perspective impact assessment. For more details, refer to Conti et al. (2021) where the LCA study of one of the farms is described in detail.
For the economic side, a cash flow analysis was used taking into consideration all the costs and revenues of the farms involved during a year. Therefore, both the consumables and raw materials used, the cost of labor and services, the depreciation of capital goods, and company production and sales were considered.
The social analysis was performed using with the social-LCA method. To this end, the UNEP guidelines (UNEP / SETAC, 2020) were followed and adapted to the present case study, selecting a series of indicators for the sector, related to four stakeholders' categories (society, local communities, workers and animals), thanks to an in-depth literature review. The reference scale approach was then used for analyzing the social inventory. The Reference Scale impact assessment provides a qualitative assessment of the social performance by attributing scores to each indicator considering performance reference points (PRP). PRP are thresholds, targets, or objectives that set different levels of social performance or social risk. In this study, context specific PRP are defined for each indicator, taking in consideration the geographic context and the economic sector. Compared with the respective reference scales, the indicators can be assigned the score: "Committed"; "Proactive"; "Compliant"; "Risky".

3. Results

The achieved results for the environmental side are in line with other LCA studies focused on pig rearing, with a GWP varying between 3.5 and 4.0 kg CO_2 eq/kg LW. Feed consumption is the main environmental hotspot for many impact categories, reaching contributions of 50-70% of the total impact for terrestrial acidification, eutrophication and particulate matter formation, and even greater than 80% for categories related to human and ecosystem toxicity (freshwater). For the GWP the contribution of the feed is lower because also the methane emitted by manure management plays an important role (30-50%).
The feed is also by far the main cost item, varying between 60 and 75% of the total, followed by the costs for work, depreciation capital goods, energy and other factors of production. Given the total production costs which are around 1.1-1.3 €/kg LW, the profit margin is quite low compared to market selling prices. A first consideration that emerges from this result is that farmers cannot easily afford investments to improve environmental and social conditions.
As for the social LCA, the farms involved appeared well aligned with the average social data of the sector, which means that most of the indicators appeared as 'compliant', therefore without a positive or negative impact. Only in a few indicators the analyzed farms demonstrated some social risks (e.g.

hours of on-the-job training), or social commitment (especially as regards the indicators linked to the *Local communities* stakeholder, demonstrating a good integration of the farms in the territory).

3.1 Alternative scenario

From an environmental point of view, on the other hand, trade-offs between different impact categories emerged. For example, as regards the GWP, the alternative scenario slightly increases its impact (although always < 5%) due to the consumption of raw materials for scrubber operation and despite the slight reduction of indirect N_2O emissions (thanks to the avoidance of part of the volatilization and soil re-deposition and denitrification of NH_3). However, impact categories linked to NH_3 emissions such as acidification and PM formation potential noticeably reduce their impact in the order of 10%. The way of modeling the co-production of ammonium solution effluent has an influence on the results. If we consider that this could replace synthetic nitrogen fertilizer otherwise bought externally by the farms, this generates a significant environmental credit. From the economic side, the installation of the air scrubber was estimated with a total cost varying between 3.4 and 17.2 €/pig place/year depending on the operation and removal efficiency. The results from the social analysis scored better for the alternative scenario, which is linked to improved values especially on the animal welfare indicators.

4. Discussion and conclusions

Methodological considerations that emerged with this study concern the fact that social analysis is certainly the one with the greater room for improvement, being the most recent methodology, and not perfectly standardized. It should also be emphasized that the inventory for environmental analysis and that for economic analysis are largely overlapped, reducing the effort of doing a combined analysis. Instead, as far as social analysis inventory is concerned, this is completely different, and it is very time consuming to set up due to the need of categories, sub-categories and indicators selection that are sector specific, and subsequently to the need of defining the social risk or commitment thresholds. Moreover, there is some sensitive information that is not always easily shared by farmers (e.g., regularity in payments, relations with local communities, etc.), which makes data collection slow and difficult. Finally, further development of the methodology is needed because the results from the S-LCA are complex to compare with those of other studies, which somewhat hinders their interpretation.

This study has shown how the pig sector, as well as, more broadly, many others within agriculture, has innumerable facets that determine different trade-offs in terms of sustainable production. Such extensive results, expressed in such a different way and not easily and directly comparable, certainly enrich the understanding of the complexity of a supply chain and highlight its strengths and critical points at different layers. Of course, on the other hand, this does not have to mean that all the results must be put at the same level of importance. It is always necessary to keep in mind the productive and socio-economic-political context within which a supply chain operates, since even this factors influence the choice the right impact mitigation actions to be undertaken.

As for the conclusions with respect to the alternative scenario, from an economic point of view the alternative mitigation scenario does not appear advantageous due to the costs of the tested technology, particularly operation costs, while not returning direct earnings to the farm. On the other hand, this triple layer analysis highlights that if the reduced environmental and social externalities were taken into account, even the "society" economic balance would improve. Future challenges will concern the analysis of how farmers can best exploit these findings economically, with an integrated vision of the three sustainability layers, favoring economic support of public institutions and / or consumers in view of their commitment to the environment.

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