ABSTRACTS BOOK

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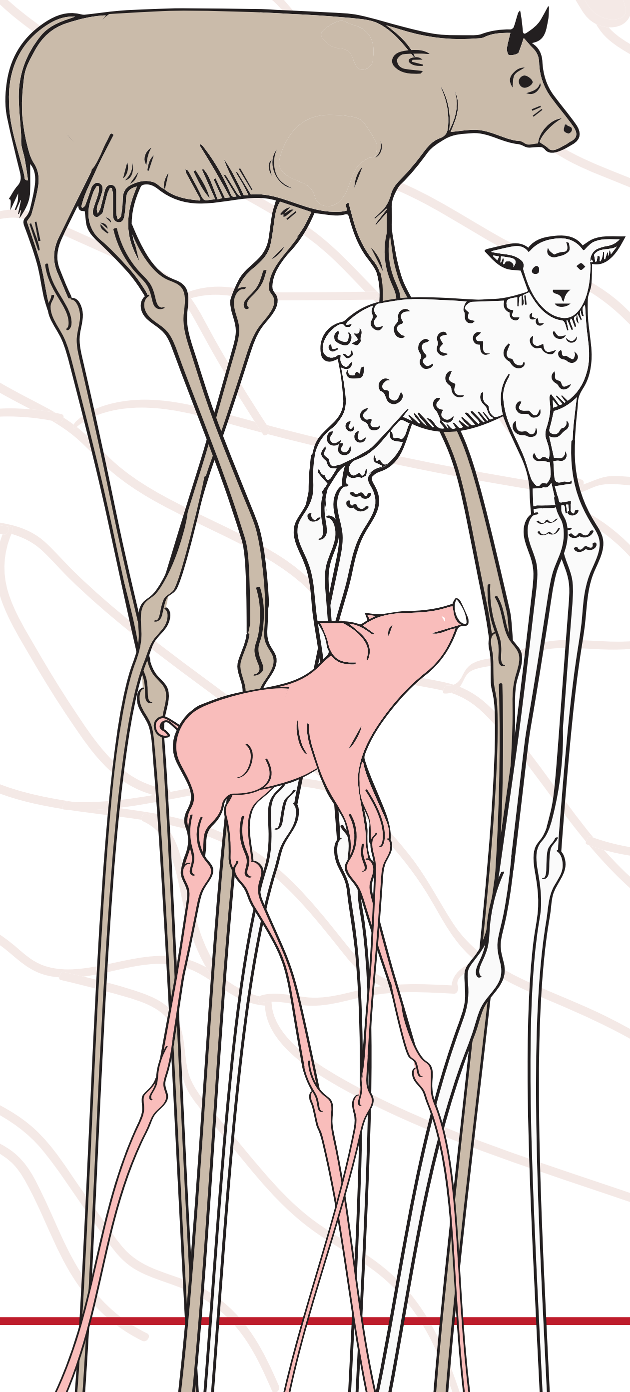

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WHAT CAN WE LEARN ABOUT THE CARBON FOOTPRINT OF PIG PRODUCTION FROM A SYSTEMATIC REVIEW AND META-ANALYSIS OF LIFE CYCLE ASSESSMENT STUDIES?

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I. INTRODUCTION

Sustainability has become a central focus in global discussions of livestock farming, particularly in relation to the environmental performance of meat production and consumption. Among livestock species, pig farming plays a significant role due to the high global production levels and efficient feed conversion, and pork and related products play a central role in consumers' food choices. However, pig farming remains a notable source of greenhouse gas emissions, primarily from feed cultivation, manure management, and on-farm energy use, which are key contributors to the carbon footprint (CF) of pork production [1–3]. To assess and compare the environmental impacts of livestock farming, including pig production, life cycle assessment (LCA) has become the standard methodological approach [2,3]. By accounting for emissions across all stages of production, LCA helps identify emission hotspots and opportunities for mitigation [2-4]. Despite the growing number of LCA studies in recent years [3,4], the data vary widely due to differences in methodologies, system boundaries, functional units, data sources, regional contexts...etc. Therefore, the lack of consolidated data has limited the ability to draw clear, generalizable conclusions about the CF of pork production and their possible integration with intrinsic pork quality properties [5]. The overall aim of this study is to address these challenges through a systematic review and meta-analysis of pig LCA studies and for the first time by considering the treatments within studies along of farming and feeding systems and other factors and/or modalities. Herein, we focus on CF impact category only. Thus, by gathering data across diverse production systems and geographic regions, this work aims providing a comprehensive overview of pig CF values.

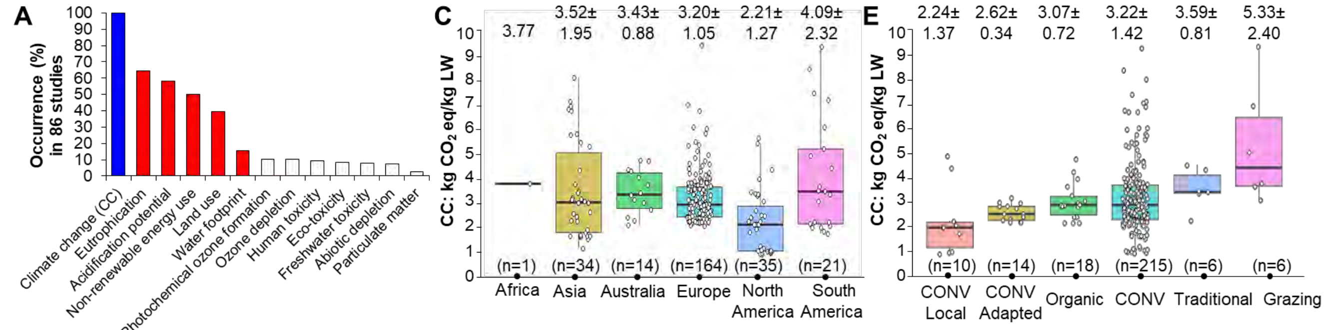
II. MATERIALS AND METHODS

To gather environmental impact data of pig farming/production evaluated through LCA and to examine how these impacts are accounted across diverse systems and factors, as well as to identify drivers of sustainable pork production with the ultimate objective of considering them with intrinsic pork quality properties within the 'One Quality' concept [5], a comprehensive literature search was conducted using Scopus and Web of Science databases. The search covered peer-reviewed articles published in English up to December 2024 and was updated in March 2025, following the standardised technique for assessing and reporting reviews of LCA (STARR-LCA) [6] and the PRISMA reporting guidelines. The search terms used were ("life cycle assessment" OR "life cycle analysis" OR "LCA" OR "carbon footprint" OR "carbon analysis") AND ("pig" OR "swine" OR "pork"). The search yielded 873 studies that were scrutinized for their eligibility along of additional papers cited in existing pig LCA literature reviews [2-4]. Studies were included if they followed ISO 14040:2006 et 14044:2006 standards, used an attributional LCA, disclosed the system boundary and defined the scope, disclosed the LCA results with functional units (FU) based on mass (kg). Papers dealing with consequential, social or nutritional LCA were excluded. A thorough reviewing of the articles with system boundaries ranging from cradle-to-farm gate (84.5%), cradle-to-slaughterhouse (15.2%) and cradle-to-port (0.6%) allowed identifying the eligible papers. Then, data related to the general information on the articles, methodological LCA framework, description of the farming systems, animal performance data, feeding strategies and/or systems, manure management systems and environmental impacts (indicators) were extracted and tabulated in an Excel spreadsheet database. WebPlotDigitizer was used to extract quantitative information from the articles that only used graphs. The data were analyzed and/or compared using both Microsoft Excel and Rstudio.

III. RESULTS AND DISCUSSION

The search yielded 86 eligible LCA studies on pig production, from which 329 observations (treatments) were identified. This work is the first to consider treatments studied in pig LCA studies compared to previous ones that focused on the average results [2-4], therefore allowing to explore/compare the impacts for several factors. Thirteen impact categories were reported (Figure 1A), mainly dominated by climate change (CC) (100%) followed by eutrophication (64%), acidification potential (58%), non-renewable energy use (50%), land use (40%) and water footprint (15%). Based on these results, we focused on CC impact category only to examine its variations within FU (Figure 1B), geographic location (Figure 1C), farming systems (Figure 1D) and feeding systems (Figure 1E) among other factors. The main FU used was 1 kg live weight (LW) and followed by 1 kg carcass weight. The FU per kg LW showed on average the lowest CC values than the four other FU (Figure 1B). These data highlighted an increase in the CC values by changing the system boundary and type of meat cut. The studies were mainly conducted in Europe followed by North America and Asia, while few have been conducted in South America and Australia and only one study was reported in Africa (Figure 1C). Overall, the average CC values were the lowest for North American, which can be related to the locally produced soy as the main protein source and not associated to deforestation.

For farming systems, conventional farming has an average CC value of 3.19±1.49 kg CO_2 eq/kg LW, but highly variable (CV: 46.71%) compared to organic (22.58%) or free range (25.52%). The results, however, did not evidence any clear



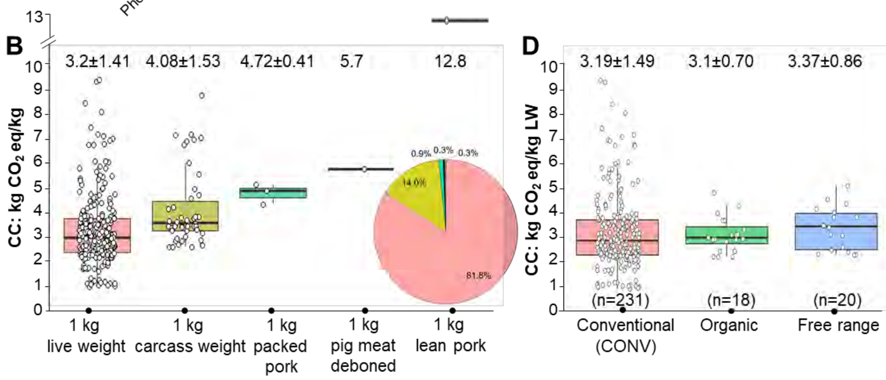


Figure 1. **A)** Environmental impact categories (%) reported in the 86 LCA studies of pig production. **B)** Comparison of climate change (CC) impact values using functional units (FU) based on mass (kg). The frequency of use of each FU is shown in the pie chart on the right. **C)** Comparison of CC values per kg live weight (LW) of pig for different geographical regions, further highlighting the breakdown of primary studies. **D)** Comparison of CC values per kg LW for different farming systems. **E)** Comparison of CC values per kg LW for different feeding systems. The average CC values ±SD are given in the top of each graph, while number of observations in the bottom.

statistical differences. In contrary, differences were observed within feeding systems (Figure 1E). The conventional local feeding (uses locally and/or on-farm produced feedstuffs) has the lowest average CC values, followed by the adapted conventional feeding (uses sustainable agriculture and farming practices and/or limited use of feed from deforested areas). Interestingly, the organic feeding system seemed to be similar in terms of CC impacts compared to conventional, but with a lower CV (23.45 vs 44.1%). The traditional (conventional feeds mixed with outdoor access and/or pasture) and grazing (pasture) systems had numerically the highest CC values.

CONCLUSION

The results of this study contribute to a deeper characterization of LCA environmental impacts of pig production. They highlighted the variations in CC within diverse FU (mainly per kg LW), geographic location, farming and feeding systems, which are ongoing to other impact categories to explore trade-offs and differences. Ultimately, the results will enable us to better understand how and through which metrics to integrate the environmental impacts with intrinsic pork qualities along of defining thresholds in multi-criteria analyses when implementing the 'One Quality' concept.

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