Janusz KRUPANEK • Beata MICHALISZYN • Manuel MORENO

ENVIRONMENTAL PERFORMANCE OF PIG MEAT PRODUCTS AND IMPROVEMENT OPPORTUNITIES. CASE STUDY FROM SPAIN

Janusz **Krupanek**, PhD (ORCID: 0000-0002-6864-9733) – *Institute for Ecology of Industrial Areas*

Beata **Michaliszyn**, PhD (ORCID: 0000-0002-6805-1678) – *Institute for Ecology of Industrial Areas*

Manuel **Moreno**, BEng, MSc (ORCID: 0000-0002-1332-9863) – *Euro Vertice*

Correspondence address:
Parque Científico de Murcia- Campus de Espinardo
Ctra. de Madrid Km 388, 30100 Murcia, Spain
e-mail: manuel.moreno@eurovertice.eu

ABSTRACT: The publication aims to assess the environmental performance of meat product and to point out the possibilities of improving the product quality in terms of its environmental impact. The research was performed within the CIRC4Life project on the example of ALIA company, Spain. The Life Cycle Assessment method and literature study were used for this purpose. The LCA was carried out for subsystems: feed production, pig housing, slaughtering, meat processing. Two scenarios: basic and improved were compared using the ReCiPe method. In the basic scenario, the highest impacts are attributed to agricultural land occupation 29%, climate change 34%, natural land transformation 11% and fossil depletion-11%. Animal feed production is the most critical phase. Comparative analysis of the scenarios showed that there is a potential for beneficial trade-offs between different impact categories by changing the processes and materials for feed production.

KEYWORDS: life cycle assessment, LCA of pork, environmental performance

 https://doi.org/10.34659/2021/4/36 JEL: Q50, Q56

Introduction

The existing studies show that the pig meat production systems contribute to increased water, soil, and air pollution. The pig meat production sector has to face many challenges related to transforming agriculture to be more friendly to the environment and the climate, which needs implementing sustainable production methods and circular business models in food processing and retail.

This publication aims to assess the environmental performance of pig meat product manufactured within the ALIA company and identify the opportunities for the improvement of its selected meat product quality in terms of its environmental impact. ALIA is an agricultural transformation society, located in La Hoya, in the centre of Guadalentin Valley, Lorca, in the Murcia region of Spain. The cooperative is currently comprised of over 900 members ranging from small family farms to large, industrial-sized agricultural enterprises. It covers, in the value chain of meat products, mainly the processes of fodder production, rearing of pigs, slaughterhouse, meat processing plant and its distribution. To some extent, it also encompasses crop production, but most of the raw materials for feed production come from the global market. The company is a part of a circular economy demonstrator, within the CIRC4Life project, focused on improving manufactured products' environmental and social performance and reducing wastes. The demonstration activities are aimed at shaping sustainable consumption patterns through the development of the environmental performance indicators of ALIA products as an integral part of the eco-labels put on these articles. For this purpose, the environmental assessment of selected pork products was performed, and some parts of this analysis are presented in this paper.

In this publication, the Life Cycle Assessment (LCA) was used. It covers the following phases of the value chain of the production of pig meat product:

- production of feed for pigs,
- farming of pigs,
- slaughterhouse activities,
- processing of meat and distribution of the products to the consumers.

The analysis was performed for two scenarios: the basic scenario which refers to the current ALIA practices and the improved scenario taking into account changes in the full life cycle of the production process aimed at improvement of the environmental performance.

An overview of the literature

Pig meat production is one of the major contributors to global environmental degradation. The pig sector is a complex system that involves fertilisers and pesticides for crop production, land transformation, transportation to and from farms, energy for processing and heat, water for animal feeding and farmyard washing, and waste management (McAuliffe et al., 2016). World livestock production has major impacts on the environment because of its emissions, which affect air, water and soil quality, and the use of limited or non-renewable resources. In this context, European Union pig production systems are facing major challenges. There is increasing public concern about the dominant intensive production systems mainly because of shortcomings in environmental and animal welfare. Due to economic constraints and globalisation, pig production systems are similar throughout the world (Dourmad J. Y. et al., 2014).

The environmental impact of pork production is the subject of many studies. These studies are carried out using a life cycle approach, particularly the life cycle analysis tool , which allows for identifying the most important impacts associated with individual phases of the manufacturing process. LCA is a useful tool for the analysis of the environmental assessment of meat products because it considers all the GHGs emitted from all stages of agricultural and food production. Apart from climate change in respect to global warming, other impacts include acidification, eutrophication, consumption of natural resources (mainly water and energy), and polluting the environment with various types of waste and wastewater discharge (Djekic I., 2015). LCA can assist in determining the overall material and energy efficiency of an agricultural system and can assist in the identification of 'hotspots' for polluting stages in production systems (Biswas et al., 2010).

The LCA analysis is focused on different phases of meat production. The main impact categories identified in the literature are: global warming potential related to emissions of methane, nitrous oxide and carbon dioxide; acidification and eutrophication potential as well as the use of natural resources, namely water and energy (Reckmann K., et al., 2012, Basset-Mens C et al., 2005, Dalgaard R. et al., Dalgaard R. et al., 2007b).

The production of feed for pigs is viewed as the main contributor to the environmental impacts of pork production in Europe causing the majority of emissions (Dalgaard, R., 2007b). According to the global LCA Study on the pig supply chain from the Food and Agriculture Organisation, feed production contributes around 60% of the emissions arising from global pig supply chains, and manure storage/processing 27%. The remaining 13% arises from a combination of post farm processing and transport of meat (6%), direct and indirect energy use in livestock production (3%) and enteric fermentation (3%) (Djekic I. et al., 2015; MacLeod M, 2013). In order to reduce the emissions from the production of pork products to the environment, it is important to make some improvements at the stage of feeding. The literature data show that the substitution of soybean products in animal feed seems to have the greatest potential for minimising the environmental impact (Reckamann K. et al., 2016). A large share of greenhouse gas emissions from using soybean products is related to crop production, transport, and land-use change which refers to the conversion of land used. The cultivation of soybeans for livestock feed manufacturing has expanded rapidly in recent years. Therefore, improving feed production in the livestock supply chain has a great potential to minimise environmental impacts.

The LCA analysis in this paper was carried out for a selected meat product: cured pork sausage Longaniza Imperial de Lorca produced by ALIA company. It is a cradle to gate analysis including also the meat processing and its distribution. Identification of key determinants of the environmental impacts were used for the optimisation of the environmental performance of the value chain. The improvements were focused on feed for fatteners composition. Two scenarios for fodder composition were compared to validate the assumptions.

Research methods

In the study, the Life Cycle Assessment (LCA) was used to assess which of the production phases cause relatively high damage to the environment. This method was also used to optimise the environmental performance in the value chain. Especially, it was used to optimise the feed recipe for pigs in order to select the feed ingredients in such a way that, while ensuring adequate nutritional value, they have a relatively low impact on the environment, taking into account both their production method and source of origin.

The LCA method and tool

Life cycle assessment (LCA) is a tool for environmental evaluation that has attracted much attention in the last decade, as it allows the comparison of different products or activities, based on the quantification of their potential environmental impacts related to the emissions of pollutants to the soil, air and water as well as the consumption of resources throughout their life cycle (Guine´e J.B., 2002). Principles of carrying out research with LCA have been given by the International Committee for Standardization in the EN ISO 14040 and EN ISO 14044. The standard PN-EN ISO 14040, refers to a life cycle assessment and a life cycle inventory analysis. The rules described in that standard should be used as the guidelines for decision making in LCA planning and running. In the standard PN-EN ISO 14044, the requirements and guidelines concerning a life cycle assessment have been given. The standard's resolutions refer to four main parts of the LCA study: defining its aim and scope, a life cycle inventory analysis, a life cycle impact assessment and an interpretation of results.

The result of an LCA study is an environmental profile of a product or activity in the form of a "score list" with environmental effects. The environmental profile shows the largest environmental problems caused by the production of a product, and at which stage(s), in the life cycle, these problems appear. The LCA process is iterative and involves revisiting previous steps when, for example, new data become available or a gap in required data is acknowledged.

In the case of agricultural systems, the LCA evaluation may be useful in practice for the decision making in the field of application of new technologies, improvement of existing products or services, marketing purposes, strategic planning and policymaking. Product designers can explore how their design choices affect the sustainability of the products.

For the purposes of the LCA of meat products, it was used the SimaPro tool, Release 8.5.2.0.

Goal and scope of analysis

The objective of this study is to assess the environmental performance of the cured pork sausage in its life cycle from the production of feed for pigs, the pig farm, via slaughterhouse to a meat processing plant in Murcia Region in Spain.

The study comprised the following steps:

- identification of relevance of life cycle phases,
- identification of the main environmental impacts of the most relevant life cycle phases,
- identification of main factors determining the impacts,
- assess the opportunities for improvement based on plans proposed by the producer.

The cured pork sausage was selected as a subject of environmental analysis because it is a very popular ALIA's meat product among consumers in Spain and is representative of a whole range of common food products.

The LCA covers the following phases of the value chain:

- production of food for pigs,
- farming of pigs,
- slaughterhouse activities,
- processing of meat and distribution of the products.

The analysis was performed in two steps which correspond to two scenarios:

- the basic scenario of ALIA current situation,
- the improved scenario in which changes have been made by the ALIA company to achieve the higher environmental performance of the assessed product.

The analysis was carried out with regard to the 18 impact categories (midpoint indicators, ReCIPe 2016 Endpoint method) and then the most important midpoint indicators have been identified using the endpoint analysis and then assessed for the main life cycle phases.

Functional unit

A comparison of life cycle environmental impacts should be based on a comparable function (or 'functional unit') to allow a fair comparison of the results. The functional unit adopted for the study is 1 kg of meat product: 1 kg of Longaniza Imperial de Lorca pork sausage - as a final product to the customer. Longaniza Imperial de Lorca is a raw Spanish sausage originating from Lorca in Murcia produced by selection and chopping of meat: lean pork, pork belly, salt, white pepper and nutmeg. This mixture is stuffed into natural, calf casings. Then the product is submitted to a controlled process of maturing and drying, which ensures good stability, as well as the characteristic colour, smell, taste and texture. Imperial de Lorca preserves the traditional and manual character of the LOS QUIJALES brand. The sausage is sold on the market in packages of about 250 g.

System boundary

The starting point for guiding LCA analysis is the exact definition of the product system by drawing the boundaries of the system, life cycle stages and the unit processes. For example, the production chains of pork cured sausage consist of different production steps: feed production, pig housing, slaughtering, meat processing. This study is a 'cradle to gate ' life cycle assessment. The consumption (storing at consumer) and post-consumption stage (waste generated after the product has been used by the consumer/waste from wasted products at consumer) are excluded from the analysis.

Within the feed production subsystem, all processes required for the production of animal fodder were considered. Feed is made from crop products, by-products, processed products and processed feeds. This sub-system includes the relevant agricultural processes: cultivation of crops, transport of crops from the place of cultivation to the processing plant, and its processing. The analysis was performed for three types of feed which differ in composition: feed for sows, feed for piglets from 6 kg to 20 kg and feed for fatteners from 20 kg to 100 kg.

Pig housing at the farm includes key activities which take place on the farm. In the farming of pigs, there is considered: feeding of sucking piglets, weaned piglets, fatteners, breeding gilts, boars and sows. The analysis covered three processes: rearing sows and sucking piglets, rearing piglets and feeding fatteners for slaughter. At this phase the direct use of manure as fertiliser was assumed as a preferable and standard method of waste disposal. In the case of dead animals disposal, the incineration method was considered. Waste management in all phases and production processes, including the dead animals from breeding, was included in the study.

Slaughtering subsystem includes key activities which take place in a slaughterhouse from reception of live pigs, covering livestock handling and animal welfare, slaughtering comprising stunning, bleeding, scalding and dehairing, evisceration, splitting the carcass, and chilling.

For the production of 1 kg of sausage, 1,35 kg of the animal must be raised and transported to the slaughtering house. As a result, only parts of the animal that are fit for human consumption are kept and the inedible parts are removed in the slaughtering process. The allocation factors for pigs' mass fractions in the slaughterhouse were used according to the Product Environmental Footprint Category Rules (PEFCRs) for pork modelling (European Commission, 2017). Waste management and the use of cleaning agents were included in this subsystem and used in the calculations.

Meat processing included all activities which take place in a processing plant, from the reception of carcasses, covering preparation activities, thermal processing, waste handling and storage of final products. The use of waste and cleaning agents were included in this subsystem and used in the calculations. Waste management and distribution of products were included in the study.

The system boundary of the LCA of meat products is presented in figure 1.

In life cycle assessment, different types of co-product allocation methods can be used. The Handbook on LCA (Guinee, 2002) advises using economic allocation as a baseline for most allocation situations in a detailed LCA. In the LCA of meat product, the economic allocation was used according to the Product Environmental Footprint Category Rules (PEFCRs) for pork modelling. This is also in line with most LCA's performed for the food sector. Economic allocation means that the shares of upstream impacts are divided between co-products based on their relative value fraction which is based on the sum of all revenues of all co-products produced in a specific production stage.

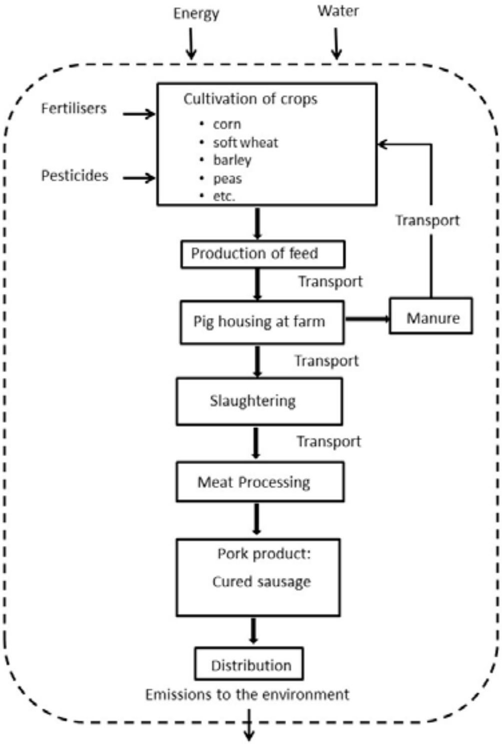


Figure 1.
The overview of the system boundary of the LCA of meat products
Source: author's work.

Allocation procedures

In order to describe how activity datasets are linked to form product systems in the ecoinvent database version3 the Allocation, ecoinvent default system model was predominantly used. It follows the attributional approach in which burdens are attributed proportionally to specific processes. Taking into account the goal of the analysis, the attributional modelling was used as this approach does not account for consequences in the surrounding market. Within this approach, all the environmental inputs and outputs are summed from raw material extraction (cradle) to the gate of the products.

Life cycle inventory analysis

Data requirements

In the first phase of the LCA, a product system is defined and in the second phase, it is filled with the inventory data. To perform an LCA all impacts of a product from cradle to gate were considered. As a rule, not only the main process chain – processes directly related to the functional unit – needed to be assessed, but also background processes like material production, energy supply, waste disposal and the delivery of services like transportation, construction, maintenance.

The inventory data in the study covered two types of data:

- foreground data on the system of primary concern were obtained from ALIA company.
- background data includes energy and materials that are delivered to the foreground system as aggregated data sets in which individual plants and operations are not identified. Background data were derived from secondary sources, e.g., literature, background databases providing average datasets, including the European ecoinvent database.

Foreground data provided by the ALIA company are included in table 1. The inventory for the individual processes and the fuel and energy balance, as well as for the unit processes of background subsystem were obtained from the ecoinvent database version 3 and Agri-footprint. In addition, output data related to main emissions, sewage and waste were obtained from the literature as well as from this database.

Assumptions and limitations

For the calculations, the infrastructure was not included. The ALIA company provided in most cases indicators, not the actual measures of the key parameters to describe the subsystems. To some extent, it was necessary to adjust SimaPro ecoinvent database version 3 selected processes for the model of ALIA system of meat production. There was no available data on the ranges of parameters and variants for the key processes limiting the sensitivity analysis.

Inventory Analysis

In this step, information on the use of resource materials and energy that are used within the life cycle, as well as the emission of substances throughout the life cycle, was collected. ALIA provided inventory data and for some parameters, the values from the ecoinvent database version 3 as well as Agri-footprint – comprehensive SimaPro database, were adjusted based on the information provided and expert knowledge and literature. The inventory includes data collection for the two scenarios of meat processing:

- the basic scenario based on current practices of rearing pigs by ALIA and meat processing,
- the improved scenario where changes have been made to achieve a higher environmental performance of the meat products.

To strengthen the sustainability of the products, the new formula of the nutritional material for fatteners 20 kg to 100 kg has been developed. Compared to the basic scenario, the amount of some components (barley, sunflower cake) decreased and in the case of soft wheat the place of origin has changed from Brazil to Europe. Instead, new ingredient has been incorporated (flour cake and beet), and the amount of corn increased by 8% in comparison to the previous formula. To strengthen sustainability, it has also been declared that there are no dead animals at the animal breeding stage. In this scenario, the use of water for the preparation of feed for piglets is not required. The thermal energy is also zero because the consistency of the fodder is in 100% flour (not granulated) as it is – it is a more efficient way of the production of animal feed.

For raw materials and bioproducts, there were used ecoinvent database version 3. Impacts of the raw materials used were included in the assessment as it was taken into account in the background information from the ecoinvent database. For fodder additives and additives in the sausage production proxy data from the ecoinvent database or own modelling based on background data from the ecoinvent database was used. Emissions to water and air from pigs rearing including manure management were based on a modified ecoinvent database – adjusted to ALIA farm structure. Foreground data on farm structure, water, feeding material energy, manure disposed and dead animals were provided by the producer. The inventory data is presented in table 1.

Table 1. Inventory data for the production of meat processing products for the basic scenario and the improved scenario

Input/output category	Unit	Basic scenario	Improved scenario
Production of animal feeding			
Corn 13%	g	1376.170	1467.805
Barley	g	693.808	659.574
Soft wheat F10	g	533.219	613.374
Peas	g	565.088	604.697
Middlings	g	242.484	255.725
Beet / sugar cane	g	24.248	-
Byproducts	g	929258	1313271
Additives	g	193.202	247850
Electrical energy	MJ	1.480	0538

Input/output category	Unit	Basic scenario	Improved scenario
Biomass	MJ	0.954	0220
Fuels	MJ	0.129	0056
Water	t	0.269	0102
Kraft paper	g	7.541	7541
Pig housing at the farm			
Transport	tkm	0164	0206
Veterinary medicine	kg	0569	0006
Heat almond shells	MJ	3704	4125
Drinking water	l	45147	25528
methane biogenic from enteric fermentation	kg	0056	0057
nitrogen monoxide - indirect emissions	kg	0001	0001
Ammonia	kg	0041	0041
particulates < 10 um	g	0455	0444
Dead animals	kg	0231	0020
Manure liquid	t	0034	0018
Subsystem Slaughterhouse			
Drinking water	l	4172	
Transport van < 3,5	tkm	0068	
Electricity	kWh	0278	
Heat natural gas 100 kW	kWh	0356	
Sewage sludge	m3	0027	
Slaughterhouse waste	kg	0009	
Subsystem: Manufacturing of products			
Electricity	kWh	1670	
Waste	kg	0029	
Drinking water	kg	6354	
Transport truck 10-20 t	tkm	0060	
Additives	kg	0179	
PE	kg	0006	

Source: author's work based on ALIA company's data.

Life Cycle Impact Assessment

In this step, the inventory data – Life Cycle Inventory results – were assessed using the SimaPro tool. Life Cycle Impact Assessment translates emissions and resource extractions into a limited number of environmental impact scores by means of so-called characterisation factors. ReCiPe 2016 method was used to calculate the product total score endpoints and midpoints to measure the environmental impacts of products. ReCiPe calculates eighteen midpoint indicators and three endpoint indicators. Midpoint indicators concern single environmental problems. In this study, the most relevant midpoint indicators have been identified using the endpoint analysis and then assessed for the main life cycle phases.

Results of the research

Basic scenario assessment

The most important endpoint impacts of the life cycle of the cured sausage (measured as mPt ReCIPe 2016 Endpoint method) analysed for the basic scenario concern human health and ecosystems. The share is respectively for human health: 32% and ecosystem 57% of the total score (figure 2). The impact on resources is relatively low (11%).

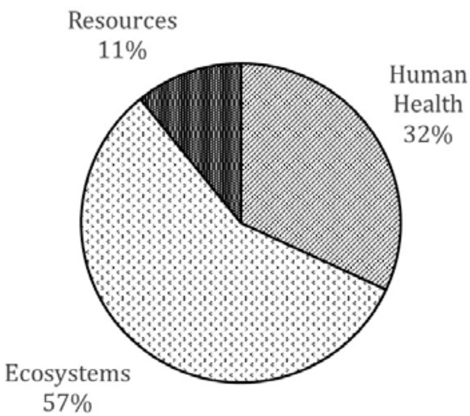


Figure 2.
Percentage share of endpoint indicators of environmental impact (expressed as single score) of the full life cycle of the cured pork sausage in the basic scenario (Recipe 2016 Endpoint method)

Source: author's work.

The main processes contributing to damage to human health are related to the feed production phase. Feed production is also the main phase contributing to damage to ecosystems. As regarding the damage to resources feed production and meat processing phases has the highest contribution.

Analysing the basic scenario with regard to the impact categories (midpoint indicators, ReCIPe 2016 Endpoint method), the most important are (figure 3):

- climate change human health,
- human toxicity,
- particulate matter formation,
- climate change ecosystems,
- agricultural land occupation,
- natural land transformation,
- fossil depletion.

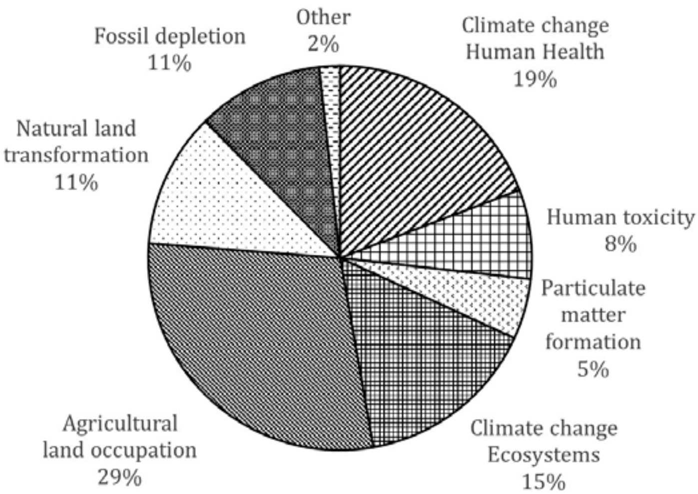


Figure 3. Percentage share of midpoint indicators of the total environmental impact (expressed as a single score – RECIPE 2016 Endpoint method) of the full life cycle of the cured pork sausage in the basic scenario

Source: author's work.

The identified impact categories constitute 98% of the total score expressed in mPt (Recipe 2016 method). The highest midpoint indicators are attributed to agricultural land occupation – 29%, climate change: 34% (ecosystems – 15% and human health – 19%), natural land transformation – 11% and fossil depletion – 11%.

The highest midpoint impacts, except for particulate matter are attributed to feeding production. It concerns especially agricultural land occupation and natural land transformation for which the feed production impact contribution is higher than 95% (figure 4e, figure 4f). The dominating role of feed production is due to extensive global networks of crops markets that are the basis for feed production (Mc Auliffe et al., 2016). It is also the case of

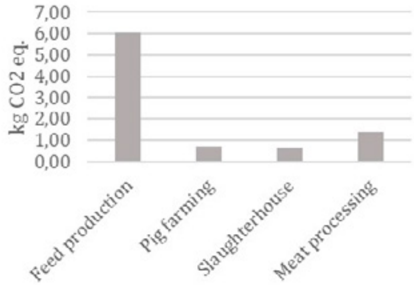
ALIA which production pattern is rather typical for Europe, where the feed production is based on global markets. In order to produce each individual ingredient, resources and energy are required and large-scale transportation networks are utilised. The dominating factors in this phase are processes of raw materials production. In the case of the Climate change (figure 4a) midpoint indicator, it is 32%, especially soybean production in Brazil (17% of the indicator). For the agricultural land occupation, 96 % of this indicator is shared by the cultivation of soybean, maise, pea, wheat grain and barley. In the basic scenario soybean, maise and wheat grain are in the biggest part produced outside of EU-27. Soybean cultivation in Brazil is responsible for 87% share of the Natural land transformation indicator. Transportation of the materials is also an important factor (11% of the total Climate change indicator) with the highest share is allocated to the feed production phase.

According to literature, the role of feed production is also viewed to be the largest contributor to environmental burdens in the pig supply chain (Mc Auliffe et al., 2016, Van der Werf H.M. et al., 2005).

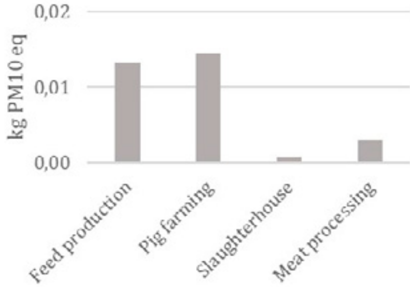
The main factor of the environmental impact of the meat production phase is caused by demand for electricity use is responsible for the climate change indicator at the level of 21% with the highest share attributed to meat processing (57%).

The human toxicity midpoint indicator (figure 4c) is attributed to agricultural production (feed production and farming) and to a lesser extent to the meat processing phase. Human toxicity is determined mostly by electricity use 30% share (where 66% is attributed to feed production) and also energy-related processes along with chemicals use especially during the production of raw materials with 77% share attributed to this phase. Fossil depletion midpoint indicator (figure 4d) is related mostly to electricity used in the meat processing and feed production phases. Particulate matter formation (figure 4b) is attributed to a variety of processes including energy-related processes and chemicals production.

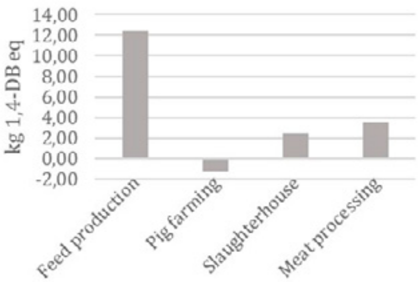
Pig farming has a relatively high impact only in the case of particulate matter midpoint indicator. The process of pigs rearing is sensitive to manure management as well as emissions to the air from the farm. In the case of ALIA manure is used as fertiliser locally in the fields. Based on the specificity of the usage (type of soil, time of application and weather conditions) the total assessment can differ up to 10%. Benefits of applying manure as fertiliser are included in the assessment. The benefits depend also on the actual content of NPK elements in the manure used as fertiliser. As a result, negative impacts on human health are avoided. Important factors are also waste treatment transportation of the manure and management practices being the cause of air and water emissions. Considering other research results, the direct application of pig manure as fertilizer is an environmentally friendly solution (Makara A., et al., 2019). According to other authors, this is of high importance shown in other studies using other interpretation tools (e.g. ILCD, CML Baseline method) (Reckamann K. et al., 2015). Slaughterhouse has the lowest values in all impact categories, and the impact is related mostly to energy and transportation.



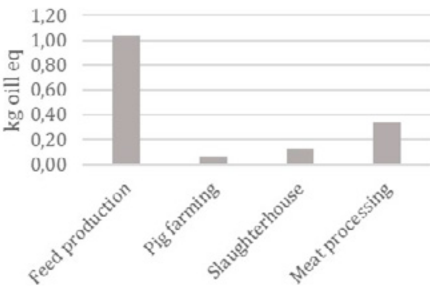
4a. Climate change



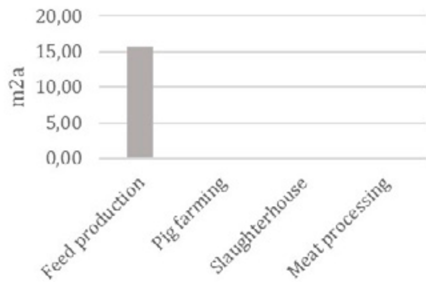
4b. Particulate matter



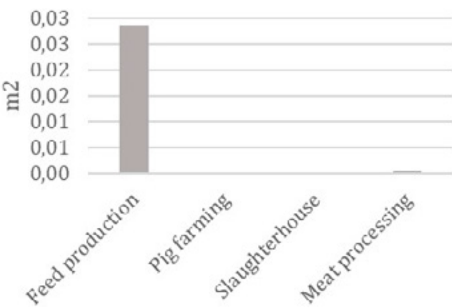
4c. Human toxicity



4d. Fossil depletion



4e. Agricultural land occupation



4f. Natural land transformation

Figure 4. Environmental impacts of the cured pork sausage per 17 categories of environmental damages – basic scenario (ReCiPe 2016 Midpoint)

Source: author's work.

The uncertainty of analysis is mainly related to the market information on crops. Assumptions had to be made as the producer provided general information about the origin of products (country). Data concerning pigs rearing, slaughterhouse and meat processing were of good quality based on company data.

It has to be noted that feed production is a more globalised burden while livestock production and waste management generate more localised burdens. Based on the results it was recommended in the first place to use waste materials from agricultural production for animal feed production and to pay attention to the origin of agricultural raw materials used for the production of feed with a preference for locally produced materials.

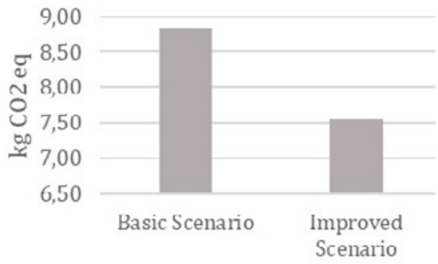
It has to be noted that the assessment is sensitive to the type of electricity mix. In the studied case electric grid mix for Spain was applied in the basic scenario. Depending on the local conditions and the company activities the potential impact might be essentially lower.

Comparison of the basic and improved scenarios

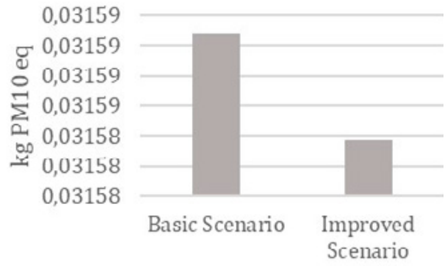
In the improved scenario, ALIA proposed the new formula of feed for rearing pigs. This scenario was compared with the basic scenario. The ReCiPe 2016 Midpoint method was used to compare the scenarios for the selected as the most relevant impact categories. Implementing the modified formula of fodder has predominantly consequences in raw materials value chains, feeding production process, and to some extent on pigs rearing.

The chart below presents a comparison of impacts midpoint indicators of the production of cured pork sausage per impact category for the two compared scenarios (figure 5). There is observed essential improvement in the impacts attributed to agricultural land cultivation including natural transformation and agricultural land occupation, and climate change.

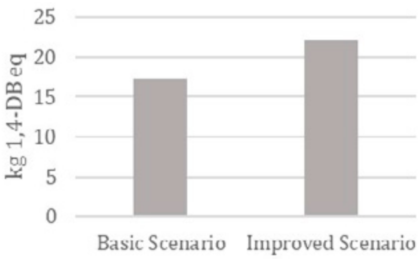
The improved scenario is slightly worse than the basic scenario for midpoint indicators: human toxicity, particulate matter and fossil depletion (table 2). It is attributed to by-products used in the modified fodder formula and higher use of feeding supplements (amino acids). The reason is that processing of raw materials and the production of feeding supplements is energy and in some cases chemicals and water-intensive. According to the producer some activities were undertaken to switch to renewable energy, and they were assumed in heat production in feed processing.



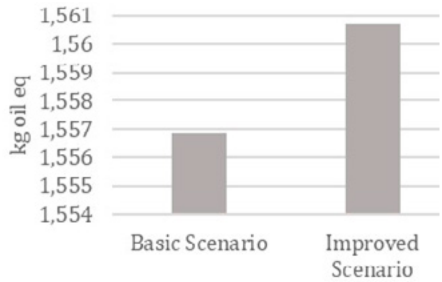
5a. Climate change



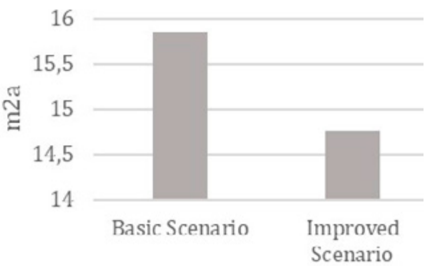
5b. Particulate matter



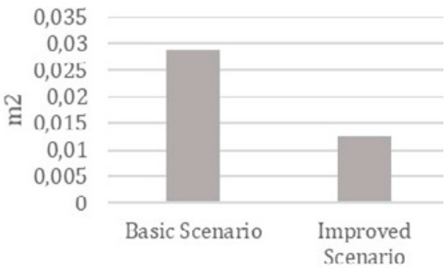
5c. Human toxicity



5d. Fossil depletion



5e. Agricultural land occupation



5f. Natural land transformation

Figure 5. Comparison of impacts of the production of cured pork sausage per impact category for the basic scenario and improved scenario (ReCiPe 2016 Midpoint)

Source: author's work.

Considering the results, it can be concluded that there is a potential for beneficial trade-offs between different impact categories by changing the processes and materials. The main trade-offs are between climate change, agricultural land and natural land transformation as mostly ecosystem related impacts versus human toxicity as human health-related impact.

Table 2. Relative change between basic scenario and the improved scenario

Impact category	Relative change
Climate change	-14.46
Human toxicity	+28.06
Particulate matter formation	-0.02
Agricultural land occupation	-6.92
Natural land transformation	-56.64
Fossil depletion	+0.25

Source: author's work.

Conclusions

The study provides insight into key factors of the environmental performance of pork meat products and the opportunities for improving environmental performance based on the example of Alia company, Spain. Meat production is an important food sector characterised by high environmental burdens. The most impactful are processes of production of agricultural raw materials use in the fodder production phase. In the studied case production of fodder in pig farming is based on global markets with a high share of inputs from Brazil, to a lesser extent from Ukraine and EU 27 countries. Changing of the fodder formula was proposed by the company to improve the environmental performance in the whole life cycle perspective of the meat product. It was based on the following assumptions:

- It is recommended to use by-products from agricultural production for animal feed production while ensuring the high quality of the feed.
- It is very important that high-quality feeds originate from food production processes based on locally available materials.
- It is crucial to pay attention to the origin of agricultural raw materials used for the production of feed. It is preferred to use locally produced materials whenever possible. Taking into account different conditions including the selected breeding technology.

From a nutritional point of view, the modified formula required adding to the fodder feeding supplements, including amino acids produced in chemical/biochemical processes. The comparative analysis showed that the new formula lowers the overall impact of meat products on ecosystems including climate change but raises slightly the impact in relation to human health indicators. It confirms that there are opportunities for improvement of the environmental performance of pig meat products nevertheless the extent of the refinement is limited due to the complexity of value chains and availability of materials related to the manufacturing of these articles.

Meat production can be improved in the pig rearing phase, although the potential environmental impact reduction is on a smaller scale but it can be important for specific environmental aspects. Pig farming causes emissions of gases to the environment related to stable and manure management and for this reason, it is recommended to use air protection solutions.

Animal wastes should be managed in a sustainable way thanks to which it will be possible to obtain maximum benefits for the company with a minimum impact on the environment. Animal manures are valuable sources of nutrients and organic matter for use in the maintenance of soil fertility and crop production. It can be also used for energy production with consecutive production of residual material from fermentation that can be used as fertiliser. Keeping the level of mortality of the stock as low as possible considering the humanitarian aspect of husbandry and implementation of effective environmentally friendly methods of the utilisation of dead animals are crucial elements of waste management.

There are also the essential aspects of energy and transport. In the studied case renewable energy for heating purposes, based on biomass from local sources was used. It was also recommended in feed production, pig farming and meat processing to use renewable electricity. One of the options might be electrical energy from cogeneration based on local sources or renewable energy from the grid.

Transport plays an important role in all phases of meat production and processes. Increasing the effectiveness of transport will minimise its negative environmental effects.

Acknowledgements

The authors acknowledge that the research for this paper is part of the CIRC4Life project funded by EU under the HORIZON 2020 programme according to the Grant Agreement No. 776503. Authors are very grateful to ALIA team for the cooperation and providing data for the analysis.

The contribution of the authors

Janusz Krupanek: conception 50%, literature review 80%, acquisition of data 10%, analysis and interpretation of data 80%, writing 50%.

Beata Michaliszyn: conception 50%, literature review 20%, acquisition of data 10%, analysis and interpretation of data 20%, writing 50%.

Manuel Moreno: acquisition of data 80%.

References

Biswas, W.K., Graham, J., Kelly, K., John, M.B., 2010. Global warming contributions from wheat, sheep meat and wool production in Victoria, Australia – a life cycle assessment. J. Cleaner Prod. 18, 1386-1392.

Basset-Mens, C, Van der Werf, H.M.G., 2005. Scenario-based environmental assessment of farming systems: the case of pig production in France. Agriculture, Ecosystems and Environment, 105,127-144, https://doi.org/10.1016/j.agee.2004.05.007.

CIRC4Life – A circular economy approach for lifecycles of products & services, www.circ4life.eu.

Djekic, I., Radovic, C., Lukic, M. Stanišić, N., Lilić, S., 2015. Environmental life-cycle assessment in production of pork products, ResearchGate https://www.researchgate.net/publication/283462496_Environmental_life-cycle_assessment_in_production_of_pork_products.

Djekic, I., 2015. Environmental impact of meat industry – current status and future perspectives, International 58th Meat Industry Conference "Meat Safety and Quality: Where it goes?, Procedia Food Science, 61-64.

Dourmad, J.Y., Ryschawy, J., Trousson, T., Bonneau, M., Gonzŕlez, H., Houwers, W.J., Hviid, M., Zimmer, C., Nguyen, T.L.T. and Morgensen, L., 2014. Evaluating environmental impacts of contrasting pig farming systems with life cycle assessment, Animal, 2027-2037, https://doi.org/10.1017/S1751731114002134.

Dalgaard, R., Halberg, N., Hermansen, J.E., 2007a. Danish pork production – An environmental assessment, DJF Animal Science. University of Aarhus – Faculty of Agricultural Sciences.

Dalgaard, R., 2007b. The environmental impact of pork production from a life cycle perspective. Institut for Samfundsudvikling og Planlægning, Aalborg Universitet.

Goedkop, M., Heijungs, R., Huijbregts, M., De Schryver, A., Struijs, J., Van Zelm, R., 2013. ReCipe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, Ruimte en Milieu.

Guinee, J., 2002. Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards, Eco-Efficiency in Industry and Science, Vol. 7, Springer Netherlands, Series ISSN 1389-6970.

MacLeod, M., Gerber, P., Mottet, A., Tempio, G., Falcucci, A., Opio, C., Vellinga, T., Henderson, B., Steinfeld, H., 2013. Greenhouse gas emissions from pig and chicken supply chains – A global life cycle assessment. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/3/i3460e/i3460e.pdf [01-09-2021].

Makara, A., Kowalski, Z., Lelek, Ł., Kulczycka, J., 2019. Comparative analyses of pig farming management systems using the Life Cycle Assessment method, Journal of Cleaner Production, Vol. 241, 118305, https://doi.org/10.1016/j.jclepro.2019.118305.

McAuliffe, G.A., Chapman, D.H., Sage, C.I, 2016. A thematic review of life cycle assessment (LCA) applied to pig production, Environmental Impacts Assessment Review, Vol. 56, 12-22. https://doi.org/10.1016/j.eiar.2015.08.008.

Polski Komitet Normalizacyjny, 20016. Environmental Management – Life cycle assessment – Principles and Framework (ISO 14040:2006), PKN Warszawa.

Reckmann, K., Traulsen, I., Krieter, J., 2012. Environmental Impact Assessment – methodology with special emphasis on European pork production. J. Environ. Manage. 107, 102-109. https://doi.org/10.1016/j.jenvman.2012.04.015.

Reckmann, K., Blank, R., Traulsen, I., Krieter, J., 2016. Comparative life cycle assessment (LCA) of pork using different protein sources in pig feed, 2016. Arch. Anim. Breed, 59, 27-36, DOI: 10.5194/aab-59-27-2016.

Van der Werf, H.M.G., Petit, J., Sanders, J., 2005. The environmental impacts of the production of concentrated feed: the case of pig feed in Bretagne. Agric. Syst. 83, 153-177.