Evaluation of allocation methods in beef and pork production at slaughterhouse level

Seyyed Hassan Pishgar-Komleh, Theun Vellinga

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Seyyed Hassan Pishgar-Komleh[1], Theun Vellinga[1]

Wageningen Livestock Research, Wageningen University and Research

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Commissioned by the European Livestock and Meat Trading Union, a study was conducted on the evaluation of allocation methods in beef and pork production at slaughterhouse level. This study focussed on the pros and cons of mass and economic fractions and allocation at slaughterhouse level for actual situations. Six slaughterhouses were studied, and the obtained results showed that mass fractions (where the focus is on edible part of slaughtered animal) are more suited to show the environmental performances over time and among slaughterhouses and can be used an incentive to improve the environmental performance of slaughterhouses. The economic allocation method affects the footprint of the edible and non-edible fractions and is more suited to be applied in the commodity chain. Our findings showed that regardless of the choice of allocation method, the use of primary slaughterhouse data for mass fractions of main-, co- and by-products needs to be allowed, which is not the case with the current JRC PEF method (latest update 2019).

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Table of contents

Foreword

The meat sector plays an important role in the world food chain and has a high contribution to the greenhouse gas (GHG) emissions. Before defining strategies to mitigate GHG emissions, identifying the share of each product on total GHG emissions is crucial. Since a large number of products and co-products are produced in the meat supply chain, identifying environmental impacts of individual products (using allocation method) is a challenging issue at slaughterhouse level. There are lots of discussions over the most appropriate allocation method which needs to be in one hand simple and easy to be applied and on the other hand robust and transparent to describe the actual situation of slaughterhouses. This allocation method can be used for benchmarking between companies and act as an incentive for improvements. Allocation is an important method to show the environmental performance of slaughterhouses. However, it is not relevant from the point of view of mitigating emissions and to improve environmental performance of slaughterhouses.

Commissioned by the European Livestock and Meat Trading Union, this study was carried out to evaluate various allocation methods in beef and pork production at slaughterhouse level. This study can shed light on the application of the mass and economic allocation method and describes the strengths and weaknesses of both methods.

This research was carried out with a close cooperation with slaughterhouses. The results presented in this report are the output of a quite number of meetings and long discussions with entrepreneurs, stakeholders of the meat industry together with researchers. The insight and viewpoints of this working group about the various allocation methods helped us to identify the strengths and weaknesses of the different methods. It was great to see an enthusiastic, active and professional team working together. We would like to thank all participants for their contribution. The cooperation and involvement of companies from different countries indicate that the results of this report can be widely implemented in Europe. We believe that this report makes an important contribution to defining a widely acceptable allocation method at the slaughterhouse level and would be the starting point for environmental improvements in meat sector.

Terms and definitions

This paragraph provides definitions for the terms that have been used in this report.

Main product – it refers to fresh meat and edible offal (including red and white offal) of the slaughtered animal which according to the regulation CE/853/2004 are used for human food purposes. In case offal is not used for human food consumption, it will be classified under the regulation CE/1069/2011. For more information see the figure below.

Co-product – it refers to food grade material including bones and fat which are being used for human food purposes. For more information see the figure below.

<table>
<tr><td colspan="4">Live animal</td></tr>
<tr><td colspan="2">Edible product</td><td>Non- edible product</td><td rowspan="5">Waste</td></tr>
<tr><td>Main products</td><td>Co-products</td><td>By-products</td></tr>
<tr><td rowspan="3">Fresh meat and edible offal</td><td rowspan="3">Food grade materials (including bones and fat)</td><td>Category 1</td></tr>
<tr><td>Category 2</td></tr>
<tr><td>Category 3</td></tr>
</table>

By-product – it refers to the parts of the slaughtered animal which based on regulation CE/1069/2011 are not intended for human food purposes. This category includes Cat. 1,2,3 by-products. For more information see the figure below.

Classification of products and by-products at the slaughterhouse level

Mass fraction – The term mass fraction refers to the fraction of a specific (main/co/by) product mass (kg) and the total mass (kg) of slaughtered animal. In other words, mass fraction is defined as "(main/co/by) product mass divided by total mass".

Mass allocation – It is a general term to indicate that mass fractions have been used for partitioning the upstream emissions to (main/co/by) products.

Economic fraction – The term economic fraction refers to the value fraction of a specific (main/co/by) product (€) and the total value of the slaughtered animal (€). In other words, economic fraction is described as "(main/co/by) product value divided by total value".

Economic allocation – It is a general term to indicate that economic fractions have been used for partitioning the upstream emissions to (by)products.

Allocation ratio – The term allocation ratio was introduced by JRC PEF which is defined as "economic fraction divided by mass fraction". The latter gives the multiplication factor to be applied to the footprint at the start of the process in order to calculate the final footprint of the (main/co/by) product. Therefore, by multiplying the upstream emissions (e.g., kg CO_2eq per kg live weight) with the allocation ratio, the environmental impact is presented per unit of (main/co/by) product (e.g., kg, ton).

Allocation factor – It is a general term to refer the mass and economic fractions.

Price fluctuation – It refers to the changes of price over time.

Technical fluctuation – It refers to the changes in mass fraction of human food (co)products and by-products as well. The technical improvement occurs when a slaughterhouse increases the mass fraction of human food (co)product by technological improvements or finding new markets. Due to the fact that the main goal of slaughterhouses is increasing the fraction of human food products, technical improvements reflect the performance of slaughterhouse. Increasing the human edible fraction is also often considered as an environmental improvement.

Summary

The meat consumption has been increasing and is likely to continue into the future. However, it has a high contribution to environmental impacts. Climate change is the major challenge for humanity in the 21st century and to overcome it, reduction of greenhouse gas (GHG) emissions is essential. Over the last decade, more attention has been paid to reduce production of GHG emissions of meat production systems. Although the slaughtering stage in the meat production and processing chain does not have a great contribution to the total environmental impact of livestock production, there is a potential for using a higher portion of the slaughtered animal in terms of edible products or by converting inedible parts to the valuable products, for instance as key elements in the pharmaceutical and medical products such as heparin. Although this does not reduce the footprint of the animal entering the slaughterhouse, it helps to reduce the environmental footprint of livestock production and consumption.

Given that the meat supply chain produces a large number of products (meat) and co-products (e.g., bones, fat, etc.), the environmental assessment of this wide range of products faces some methodological issues. Allocation (the partitioning) of upstream burdens between various (by)products at the slaughterhouse gate is a challenging issue. There are many discussions over the most appropriate allocation approaches. Industries feel the need for a level playing field and for a simple, robust and transparent allocation method. Such an allocation method will describe the actual situation well, support benchmarking between companies and act as an incentive for improvements. Therefore, the allocation not only should be based on their scientific aspects, but also on the process aspects, such as acceptance, transparency and applicability. Since the environmental footprints of meat (by)products directly are affected by the applied allocation method and also various allocation methods are applicable, this study aims to have a better evaluation regarding application of different allocation approaches. Therefore, the goal of this study was to analyse differences between mass and economic allocation approaches using data from slaughterhouses in Europe. Data including the mass and price of different (by)products of slaughtered pig and beef were collected from six slaughterhouses in Europe over 2015-2020. To have a broader overview and better insight about the changes in slaughterhouses over a longer period, data for 2005 was also collected.

Evaluation of mass fractions showed that on average for pig slaughterhouses about 80% and for beef slaughterhouses about 65% of total mass of the slaughtered animal are used for human food purposes. Some variations of mass fraction for (by)products were seen over the last years which underlined the improvements in performance of slaughterhouses, when it comes to increasing the edible parts of the animal. The obtained results also showed that for by-products (inedible parts), the mass fraction differs from company to company. In contrast, the economic fraction could not show the existing difference among slaughterhouses. Studying the variation of mass fraction of (by)products over time illustrated that the fixed mass fractions as applied by the JRC PEF method do not reflect the actual situation, where the small and large-scale slaughterhouses exist and where companies have been able to improve their slaughtering process. Moreover, it does not work as incentive for slaughterhouses to improve their performance and undertake efforts to increase the edible part. An approach with flexible mass fraction and fixed prices was tested for different scenarios and it was revealed that this approach can reflect the environmental improvements of slaughterhouses, but the indirect impact of changes in the mass fraction of by-products on allocation ratio of human edible products needs to be considered.

Based on the obtained results, the economic fractions suggested by JRC PEF is more aligned with the actual situation. However, the economic fractions can still not capture changes over time and differences between small and large-scale slaughterhouses. Therefore, it cannot be used as an incentive for slaughterhouses to improve their performance. The high prices of human edible products compared to the inedible products result in high economic fractions of the edible part which cover the differences. Therefore, the economic fraction does not reflect the performance of the slaughterhouses and is not suited to be applied for benchmarking or as an incentive. As a general conclusion the fixed mass allocation fraction suggested by JRC PEF does not cover the actual situation.

In addition to the mentioned issue, JRC PEF considers no allocation fractions for by-products (Cat. 1, 2 and waste) with zero or negative economic value however, these by-products might be used for production of other products. Therefore, after processing they receive an economic value. By subtracting the processing costs from the final value of product, the economic value of Cat. 1, 2 and waste at slaughterhouse gate can be determined (or estimated) and this value can be used for further calculations related to allocation.
Both mass and economic fractions have their own advantages and disadvantages to be used for allocating the upstream emissions to (by)products. In this report we discussed them in detail, and we provide an approach for using mass or economic allocation methods for different situations. Depending on the aim, one of the allocation approaches can be selected and applied. Economic fractions provide more stability, however, cannot show the performance changes of slaughterhouses and cannot be used for benchmarking of slaughterhouses. Economic fractions preferably can be used for allocating upstream emissions (emissions associated with the husbandry and slaughtering stage) to different economic sectors (pet food, leather, etc.) and using allocation ratios (economic fractions divided by mass fractions as it has been described by JRC PEF) the allocated emissions per kg of (by)product can be determined. In case the goal is benchmarking or incentivizing the slaughterhouses to increase the fraction of human food products, mass fractions can be applied.

In addition to selecting the allocation method, it is important to make a decision between fixed allocation ratios and flexible ones. Our scenario analysis showed that flexible mass fraction in JRC PEF structure can show the performances of slaughterhouses. However, the allocation ratio is affected not only by a change in the mass fraction of edible parts but also by a change in the fraction of other by-products. Variations over time and scale in slaughterhouses can be considered as the shortcomings of fixed allocation ratios. The fixed ratios hide the variations over time and therefore cannot reflect the actual situation. Therefore, no matter which allocation method is used, five years moving average for mass and price values are suggested to be applied for further calculations.

1 Introduction

Compared to the farm stage, the slaughtering process has been less considered from an environmental point of view. This is linked to the fact that slaughterhouse activities only play a minor part of the environmental impact compared to the upstream emissions of animal production at the farm stage (Dalgaard *et al.*, 2007), and because the slaughtering stage is often viewed merely as a distribution question among sectors. Generally, the slaughtering process leads to two main categories of products including edible and inedible products. Depending on the regional eating habits around the world, carcass components are classified into each category. Slaughterhouses are responsible for certain amounts of greenhouse gases (GHGs) associated with the electricity used to run the slaughterhouses, packing, cooling, heating cleaning water and transporting the slaughtered animals as well as getting rid of the wastewater. Although the slaughtering stage does not have a great contribution to the total environmental impact of meat products (Dalgaard *et al.*, 2007; Nguyen *et al.*, 2011), there is a large potential for reducing the environmental impacts. Mogensen *et al.* (2016) identified a large mitigation effect of 17-23% GHG emissions per kg edible product when utilizing more of the slaughtered animal for edible products. Increasing the share of live animal for human food purposes is also in-line with the food waste hierarchy. Converting inedible parts to the valuable products that can be used for a number of purposes like the medicine products, electricity or heat via biogas, biodiesel, etc is also very important. It is reducing the production of similar synthetic products and in other words is creating environmental credits (Mogensen *et al.*, 2016). This also contributes to the waste reduction agenda. Life Cycle Assessment (LCA) is the method to calculate the environmental impact of production (ISO, 2006). The partitioning of emissions (allocation) is an important methodological choice leading to uncertainty and variation in the LCA results. Allocation at slaughterhouse level also faces methodological issues such as product categorizations, partitioning of upstream burdens between various products and by-products after the slaughtering process, and how to identify an allocation method supporting and incentivising environmental improvements at slaughterhouse level, including an increase of the edible parts of the slaughtered animal, which is an important contribution of the slaughterhouse sector. To allocate the upstream emissions to different (by)products, different allocation methods are applied, and also scientific literature does not provide a uniform approach, as will be shown in *Chapter 2*. Economic and mass allocation are most applied in the slaughterhouse sector. Therefore, this study aims to evaluate both economic and mass allocation approaches at slaughterhouse level to identify the strength and weakness of the approaches. More specifically, this study focusses on:

- Calculating the mass and economic allocation factors (mass and economic fractions) for different categories of slaughtering products for pig and beef.
- Comparing the allocation factors suggested by the JRC PEF with the actual situation.
- Studying the impact of technical and price fluctuation on mass and economic allocation factors.
- Studying the variation of allocation factors among various companies (with different scales) and countries.
- Conducting a comparison and a sensitivity analysis about the applied allocation methods at slaughterhouse level, discuss the advantages and disadvantages of both systems in order to find a robust, stable and easy applicable allocation method being able to reflect actual slaughterhouse situations and incentivizing industries to improve their environmental performance.

Reader's guide

A natural starting point for discussing the allocation issue is the allocation hierarchy as presented in ISO 14044, which *Chapter 2* will touch upon. This chapter will also include how different studies have incorporated the various allocation methods and provides a summary at the end of the chapter. Hereafter follows a review of allocation methods in different guidelines. *Chapter 3* covers data collection and consideration hereof for the sensitivity analysis. *Chapter 4* provides an overview of the mass and economic fraction fluctuation for beef and pig slaughterhouses. *Chapter 5* focusses on differences between slaughterhouses in terms of mass and economic fractions. Both large- and small-scale slaughterhouses are included for both species, to identify any potential difference when it comes to fluctuations. *Chapter 6* is a historic overview of the increase of the edible parts of the animal at the slaughterhouse-level. The findings in *Chapter 4* will hereafter be compared with the allocation methodology at slaughterhouse level in the Joint Research Centre Product Environmental Footprint (JRC PEF) method (Zampori and Pant, 2019) in *Chapter 7*. In *Chapter 8*, general discussion will be provided, and the pros and cons of the different allocation methods are discussed. Finally, a conclusion is presented in *Chapter 9*.

2 Allocation methods in literature

The meat supply chain (from the cradle to the slaughterhouse gate) produces a large number of products (meat) and co-products (e.g., bones, leather, etc.). The environmental assessment of this wide range of products faces some methodological issues such as allocation of upstream burdens between various products and by-products after the slaughtering process. Allocation is one of the most challenging issues in modelling the environmental impact of livestock production at the slaughtering level. For this reason, ISO 14044 provides a mandatory hierarchy for dealing with co-production as follows (ISO, 2006):

> "*Step 1*: wherever possible, allocation should be avoided by (1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes or (2) expanding the product system to include the additional functions related to the co-products.
>
> *Step 2*: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them, i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.
>
> *Step 3*: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products."

As ISO 14044 recommends, the first choice in a multi-functional system is the avoidance of allocation by sub-division or the system expansion where possible (ISO, 2006). The idea of avoiding allocation by expanding the system has been put forward by Tillman *et al.* (1991) and Vigon *et al.* (1993). In this method, allocation is avoided and all co-products, together with what they displace, remain within the system boundary. Co-products are considered to displace marginal production of an equivalent quantity of the same function, where the displaced product is the main product of that alternative system, which is the option 2 in step 1. By subtracting the inventory of the displaced product from the multi-functional system, the net inputs and outputs of the determining product of the system under study can be calculated. The strength of the system expansion is that it can reflect both the physical and economic implications of all coproducts. However, in a complex production system the high data requirement can be a weakness for this method and can lead to a low level of transparency. Moreover, in the case of which there are different possibilities of the system expansion different results will be obtained (ISO, 2019), implying that allocation results depend on the choice of the sub system.

According to the ISO 14044, when system expansion is not applicable, a physical i.e. causal relationship between the inputs, outputs and co-products can be identified and applied for allocation and it will be the most reliable approach (ISO, 2006). In the physical (biophysical) allocation, the allocation factors are relatively stable however, when different relationships can be identified, different results can be expected. Also, interpretations based on physical allocation are disconnected from the business reality. Theoretically, biophysical allocation is applicable for co-products at slaughtering level and attempts have been made to develop a method (Chen *et al.*, 2017). However, no applicable and reliable method has been introduced for biophysical allocation at slaughtering level yet. The first step in biophysical allocation is the mass-based partitioning of all slaughter co-products, which is also the fundament for the mass-based and the economic allocation. Due to this fact that there is no significant difference between the carcass components at slaughterhouse level in terms of their compound's traits, it is unclear if the biophysical method is applicable at this level.

Mass allocation is another method which can be applied. Mass allocation is based on the weight of all (by)products except for the ones which are classified as waste or by-products category 1 and category 2 (for explanation, see list of definitions). To control and monitor the production flows and also identifying and reducing losses, slaughterhouses have a mass-based monitoring system. Therefore, applying an already existing system (mass-based) for the environmental allocation makes it easier and non-costly. However, it is a discussion point, whether an allocation solely based on mass would provide an incentive to increase the edible part of the animal, especially when the environmental impact is viewed per unit of (by)product (ton, kg, etc.). This will be discussed extensively in the next chapters.

Besides mass allocation, economic allocation is another method. Economic allocation is the most commonly reported allocation method in published agricultural LCA studies (Thomassen *et al.*, 2008; De Vries and de Boer, 2010). Economic allocation is the specific method at slaughterhouse level in the JRC PEF guideline (Zampori and Pant, 2019). Economic allocation especially at slaughtering level has some problems that need to be considered. For example, depending on the region and the country, some co-products which are not reused in the production of other products, do not have any economic value. Also, the variation in slaughter fractions will affect the final results. In this situation, by applying economic allocation, all environmental burdens are allocated to the products with an economic value, while by-products without or with little economic value still can have a value from an agronomic or ecological point of view. Another problem is instability due to price fluctuations. Prices vary considerably depending on unpredictable circumstances (i.e., embargos, new market penetration, pandemics, and etc.). The economic value of the slaughtering products is highly variable over locations and depending on the use of these by-products (e.g., human or pet food). A good example is the greater economic value of different edible products in East Asia compared to Europe. As it has been mentioned in the last amendment of ISO 14044 (ISO, 2019), application of economic allocation depends upon having market prices for all (by)products at the point of co-production. To overcome the mentioned issues regarding the economic allocation, some solutions have been provided in this version of ISO 14044 (ISO, 2019). In the case that the prices of some (by)products may be volatile, it is strongly recommended to determine an average price over a relevant time interval (ISO, 2019). In a case a by-product may not have any economic value at the slaughterhouse gate, it is suggested to estimate the economic value of the by-product after a further processing stage. In such cases, the economic value of by-product can be estimated by subtracting the cost of further processing, packaging or transportation from the eventual market price of a final product (ISO, 2019). In general, economic allocation will not reflect the physical causalities of a specific product. In the following chapters all the mentioned issues will be discussed extensively.

2.1 Allocation approaches in different guidelines

Many guidelines interpreted the ISO standards in more details such as ILCD Handbook (JRC, 2010), the BP X30-323-0 standard (ADEME, 2010), the JRC PEF Guide (Zampori and Pant, 2019), the PAS 2050 specification (BSI, 2011), and the Greenhouse Gas Protocol (WRI/WBCSD, 2011). To have a comprehensive overview about the allocation approaches and to better illustrate the methods and the underlying assumptions, the allocation methods suggested by the relevant guidelines at slaughterhouse level are discussed in following paragraphs.

2.2 Product Environmental Footprint

Economic allocation is the specific method at slaughterhouse level in the Joint Research Centre Product Environmental Footprint (JRC PEF) guideline (Zampori and Pant, 2019). The allocation factors for beef are established for the six product categories namely fresh meat and edible offal, food grade bones, food grade fat, Cat. 3 by-products, hides and skins, and Cat. 1/2 material and waste. In relation to food grade bone and fat a more detailed explanation should be considered. If allocation factors are desired to subdivide the impact of the carcass among different cuts, these subdivisions of carcass cuts need to be defined and justified in the context of the JRC PEF method. Generally, no allocation is performed for all animal by-products treated as waste according to the Circular Footprint Formula (CFF). The JRC PEF provides default allocation factors (Table 17 from Zampori and Pant (2019)) for different by-products and the change of allocation factor is not allowed. These fixed allocation factors should be applied for different animal species. The environmental impact per unit of product is calculated as following:

$$EI_i = EI_w * AR_i \quad \text{Eq. 1}$$

$$AR_i = EA_i / MF_i \quad \text{Eq. 2}$$

where, EI_i is the environmental impact per mass unit of product *i*, (*i* = a slaughterhouse output listed above), EI_w is the environmental impact of the whole animal divided by live weight mass of the animal, AR_i is the allocation ratio for product *i*, EA_i is the economic fraction of product *i* and MF_i is the mass fraction of product *i*.

For pork, a similar approach is suggested while the product categories include fresh meat and edible offal, food grade bones, food grade fat, Cat. 3 slaughter by-products and hides and skins (categorized in Cat. 3 products). The default allocation factors for pork are presented in Table 18 of the JRC PEF (Zampori and Pant, 2019).

2.3 Footprint Category Rules for Red Meat

A lot of work has been done by the European Livestock and Meat Trades Union (UECBV) to improve the environmental performance of EU livestock industry. Recently, a harmonized, comprehensive and science-based methodology called Red Meat Footprint Category Rules (FCR RED MEAT) was introduced by the UECBV, to calculate the environmental performance of the European livestock and meat sector (UECBV, 2019). The aim of this guideline was calculating the environmental performance of the European livestock and meat sectors (UECBV, 2019). The basic rule for partitioning the environmental burdens is mass allocation based on 'weight as is' for all (by)products except for the products which are classified as waste or by-products Cat. 1 and by-products Cat. 2 to be rendered. To conduct the allocation at the slaughterhouse, the main product "red meat" and other (by)products and wastes should be categorized in the product groups namely 1) products used for human consumption, 2) hides and skins, sold to leather industry, 3) products for animal feed applications, such as pet food or feed for fur animals, 4) products sold to pharma industry, 5) products sold for rendering, 6) products sold for biogas production. The time period for collecting slaughtering data should not be less than 3 years.

2.4 European Pet Food Industry Federation

The European Pet Food Industry Federation (FEDIAF) introduced a methodology to assess the environmental impacts of their pet food products. For dividing the environmental burdens between meat and animal by-products an improved economic allocation approach was developed. In this approach all the slaughtering products are categorized as meat (human consumption products) and by-products (non-human consumption products). For beef, leather was categorized separately. In this approach the economic allocation method relies on the price fraction, not absolute prices, so calculations can be done using indices and ratios while keeping actual prices confidential. The price fraction for meat product was defined as the fraction of meat price and by-product price. In this approach the price fraction of a by-product was considered as one. Prices are first averaged (on a weight-adjusted basis) within each group and then the price fraction is taken. As it is claimed, one of the key benefits of using price fraction is that because the prices within a group are aggregated/averaged and then the price fraction is calculated, the final value is less sensitive to short term changes in the price of a single fraction; so, there is no need to continually adjust emissions factors as prices change in the marketplace. For the rest of calculations, the JRC PEF rules for the economic allocation were applied and ultimately the allocation ratio was defined (Eq. 2).

2.5 Livestock Environmental Assessment and Performance

The Livestock Environmental Assessment and Performance (LEAP) guideline suggests choosing economic allocation for slaughtering products. However, mass allocation may also be examined to determine the robustness of the results to the choice of allocation methodology. From a consumer perspective, there is a difference in the products derived from a cull dairy cow and finished steer. However, from a nutritional perspective, there is little difference, and all serve an equivalent nutritional value. Therefore, in the LEAP guidelines, all edible products through the supply chain are considered as equivalent, and other products are classified in groups according to their function or market (e.g. pet foods or livestock feeds, tallow for biodiesel and hides for leather) (FAO, 2016).
For pork, LEAP guideline suggests separating the activities specific to individual products where it is possible. In a case an allocation method needs to be applied, the economic allocation is recommended, possibly based on a five years of recent average prices (FAO, 2018).
The result of our literature scan in various related guidelines showed that there is no consensus on the allocation approach. Moreover, various classifications are provided by different guidelines for products and by-products at slaughterhouse level which makes the allocation more complex.

2.6 Allocation issue in research articles

In this section, the allocation related issues discussed in the previous research are presented. Many studies applied different allocation methods in livestock production, however, few assessments were on slaughtering level. Cederberg and Flysjö (2004) calculated the environmental impacts of the pig farming system at the end of the slaughtering process and allocated all environmental impacts to the main product (one kg of bone and fat free meat) and ignored co-products. Vitali *et al.* (2018) applied economic allocation to allocate the carbon footprint of organic beef meat (including slaughtering) to various products. Economic allocation is the recommended method by the LEAP Guidelines for beef products at post-farm gate (FAO, 2016). Bondt *et al.* (2020) developed rules for the calculation of the carbon footprint for pig production through the whole life cycle i.e., fattening, the slaughterhouse and meat-cutting stages. They applied economic allocation. To make the allocation method robust, consistent and transparent, a 5-year moving average price was recommended for each by-product. To allocate the total environmental impact of beef production systems to various products at slaughtering level, Mogensen *et al.* (2016) applied a combination of system expansion and economic allocation. The system boundary was expanded to include the processes in which co-products were reused. By subtracting the environmental burden of displaced products from the multi-functional system, the environmental impact of the main products was calculated. For the rest of the products, economic allocation was applied. Chen *et al.* (2017) developed a biophysical allocation method to assign the environmental burdens to different the livestock co-products at the slaughterhouse level based on their metabolic energy

requirements. Their method considered the energy cost of building and maintaining the tissues, regardless their final use. Besides the studies have been conducted in the meat sector, some efforts have been started to provide more robust methodology to integrate the environmental and nutritional aspects in the food system. Recently the Food and Agriculture Organization of the United Nations (FAO) (McLaren *et al.*, 2022) published a report which aimed to discuss and provide guidance on how to combine the environmental and nutritional aspects of food system to support decision makers.
Comparison of different allocation methods has been conducted in some LCAs. Esteves *et al.* (2017) applied mass, market value and energy content to allocate the GHG emissions from slaughtering and rendering process to different products. The results showed a big difference between the allocation factors of different products. Aguirre-Villegas *et al.* (2012) applied the LCA methodology to estimate the global warming potential and the energy intensity for a multifunctional system, in which both cheese and food-grade whey are produced. They applied subdivision, allocation fractions, and a method that combines both subdivision and allocation fractions to handle co-product multifunctionality. The method that combines subdivision and allocation was presented as the preferred and most accurate method to deal with the multifunctionality of cheese and whey manufacturing. Kodera (2007) studied the impact of applying different allocation methods on bioethanol LCA results and found that the impact can be large in some feedstocks. Avoiding allocation showed to address the lowest environmental impact whereas mass allocation showed the greatest impact on the bioethanol.

In the mass and economic allocation methods, price and technical fluctuations (changes in mass fractions of different animal parts) will affect the allocation factors. To the best of our knowledge, no research has been conducted on the impact of price and technical fluctuations on the allocation factors of slaughtering products. Therefore, a sensitivity analysis related to price and technical fluctuations helps to determine the robustness of different allocation methods against these changes.

Moreover, a literature review shows that there is no agreement on one specific method for the allocation. Applying various methods will have a substantial impact on the environmental load of a specific product, while the total load of the production system will not change (FAO, 2016). Also, it is claimed that due to variations, the standard fractions provided by the JRC PEF to be used for economic allocation (Zampori and Pant, 2019) don't reflect the actual situation of slaughterhouses and ignore the differences between animal breeds and activities in slaughterhouses. According to the ISO 14044 recommendation, when several alternative allocation methods are applicable, a sensitivity analysis should be conducted to evaluate the impact of different allocation methods on the LCA results (ISO, 2006).

Beside the technical aspects of allocation, it is known that also social and business aspects play a role, which is an important reason for the lack of agreement. Industries feel the need for a level playing field and for a simple, robust and transparent allocation method supporting benchmarking between companies and acting as an incentive for improvements. It means that the choice of allocation not only should be based on their scientific aspects, but also on the process aspects, such as acceptance, transparency, applicability, and ability to be a driver for improvements in a sector, as mentioned in the *Chapter 1*.

To sum it up, with respect to this fact that the results of environmental assessment for (by)products at the slaughtering level are affected by the applied allocation method and also various allocation methods are applicable and each method has its own advantages and disadvantages, it is crucial to have a better evaluation regarding application of different allocation approaches. Although system expansion and biophysical allocation are higher in the allocation hierarchy, both approaches still struggle with methodological issues such as the choice of sub-system or in fact extend the mass allocation system which are considered as a disadvantage. For this reason, we limited the comparison to mass and economic allocation.

3 Data collection and processing

3.1 Data collection

To conduct a sensitivity analysis, data were collected from six different slaughterhouses for beef, veal and pork in different European countries over 2015-2020. Due to confidentiality concerns, no further details are provided about the slaughterhouses. The collected data consisted of the mass and price of different products and by-products of slaughtered pig and beef. One of the important steps in calculation of allocation factors is classifying the slaughterhouse by-products. The slaughtering products are divided to six main categories according to the JRC PEF guideline (Zampori and Pant, 2019) and the FCR RED MEAT (UECBV, 2019) (Figure 1), as follows:

- Fresh meat and edible offal.
- Food grade materials (bones and fat): Carcasses and parts of animals slaughtered which are fit for human consumption.
- Category 1: Risk materials, e.g., infected/ contaminated animals or animal co-products.
- Category 2: Manure and digestive tract content, products of animal origin unfit for human consumption.
- Category 3: Carcasses and parts of animals slaughtered and which are fit for human consumption but are not intended for human consumption for commercial reasons, including parts of animals slaughtered that can be used for various by-product processes (e.g. animal feed, medicine, biodiesel and biogas products) and also skins and hides going to the leather industry (note that hides and skins may also belong to other categories depending on the condition and nature that is determined by the accompanying sanitary documentation). There is a thin line between food grade and category 3 materials, shifting products to human consumption will affect the allocation.
- Waste: parts of animals slaughtered which is discards or intends or required to discard.

However, in this study, the categories fresh meat and edible offal and food grade bones and fat have been placed in one category as human food or edible products. This is of course something that will be further touched upon, when comparing the JRC PEF method and the actual situation.

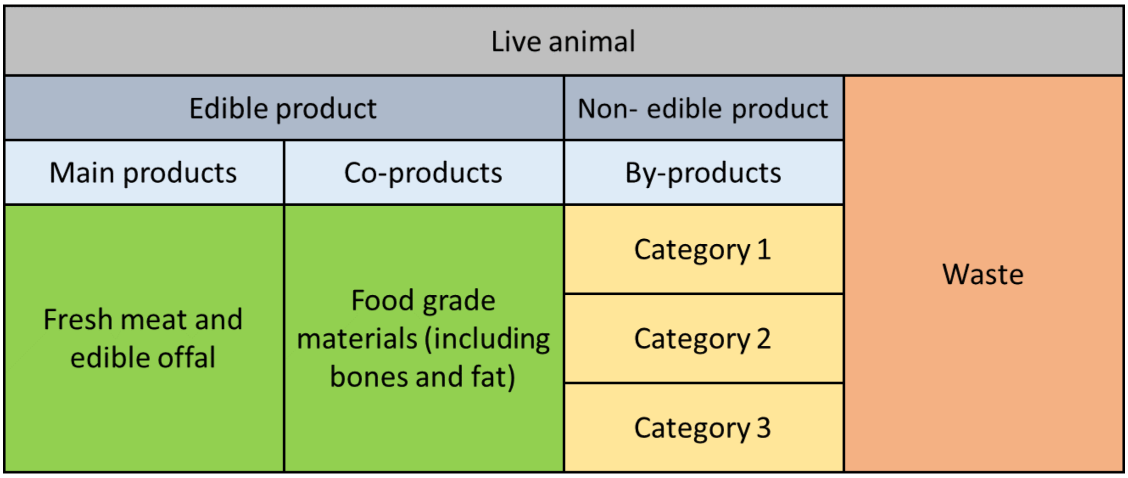

Figure 1 *Classification of products and by-products at the slaughterhouse level.*

In order to assess the longer-term historic developments in the mass fractions of edible products, data on mass fractions of (by)products were collected for the period between 2005 and 2015.

3.2 Data processing

Given the high variation of products and by-products at the slaughterhouse level, and the different terms that are used for naming the parts of the slaughtered animal, it is crucial to apply a consistent approach for data collected from slaughterhouses. To have a consistent approach for the data collection step, we classified the products and by-products based on their target market namely human food, animal feed (pet and fur food), biogas and compost, rendering and biofuel production, hides and skin, and pharmaceutical products. In this method, regardless of the product category the target market of the product is considered. Therefore, it is easier to show the environmental performance (or improvement) of slaughterhouses over time by comparing the fraction of the slaughtered animal parts which is used for human consumption. For each category the mass of all products at slaughterhouse level was determined over months and years. Given the low variation over months, the average quarterly based figures were applied for further analysis. The economic value (price) of the (by)products were collected from company databases.

To show the robustness of mass and economic allocation approaches, the variation of mass and economic fractions over years and among slaughterhouses were studied, see Eq. 1 and Eq. 2. The variation of mass and economic fractions is the term which will be discussed widely in this report and needs to be fully defined. Variation in mass and economic fractions occur due to price fluctuation, market fluctuation and technical improvement (increasing the fraction of human food products). To show the variation of mass and economic fractions in a slaughterhouse, the mass and price of all (by)products were collected over 2015-2020. To gain insight into the variability among slaughterhouses, we compared the small- and large-scale slaughterhouses. It is challenging to define small and large-scale slaughterhouses. Slaughterhouses have been categorised on their annual production and also on their access to international markets. Small-scale slaughterhouses are the ones with lower level of yearly production and limited access to the markets outside the country and almost all their products are sold to the domestic markets while the large-scale slaughterhouses have access to broader markets with a higher yearly production. The comparison between small- and large-scale slaughterhouses was carried out for both pig and beef slaughterhouses.

The data of the period before 2015 have been categorized in the same way as more recent data. These data have been used to show the technical changes in the slaughterhouses and their efforts to increase the fraction of human food fractions.

4 Variation in mass and economic fractions in pork and beef slaughterhouses

In this section the variation of mass and economic fractions due to technical and price fluctuations is presented. The study was conducted for both pig and beef and the results of the price and technical fluctuation for two pig and two beef slaughterhouses are presented in this section. Due to the fact that less detailed information was provided by two slaughterhouses (one pig and one beef slaughterhouse), the results are presented for four slaughterhouses. The aim of this chapter is providing more detailed information about the variations in slaughterhouses.

4.1 Variation in mass and economic fractions in pig slaughterhouses

Figure 2 to Figure 5 show the variations due to technical and price fluctuations for two different pig slaughterhouses. Figure 2 shows the mass fraction and its variation for different groups of products and by-products between 2015 and 2020 for the pig slaughterhouse 1. As it is seen, human food products had the highest mass fraction (grey line, scale on right axis) (on average 88%) and followed by pet food (7%), rendering and biofuel (4%) and biogas and compost groups (1%) (scale on left axis). The mass fraction of human food products varied between 86% to 89% over the 6 years period. Among the other products (inedible parts), the highest variation was seen for the rendering and biofuel group (3%) and followed by the pet food group (1%). For the other product groups the variation was low or their share to the total mass of the slaughtered animal was very low.

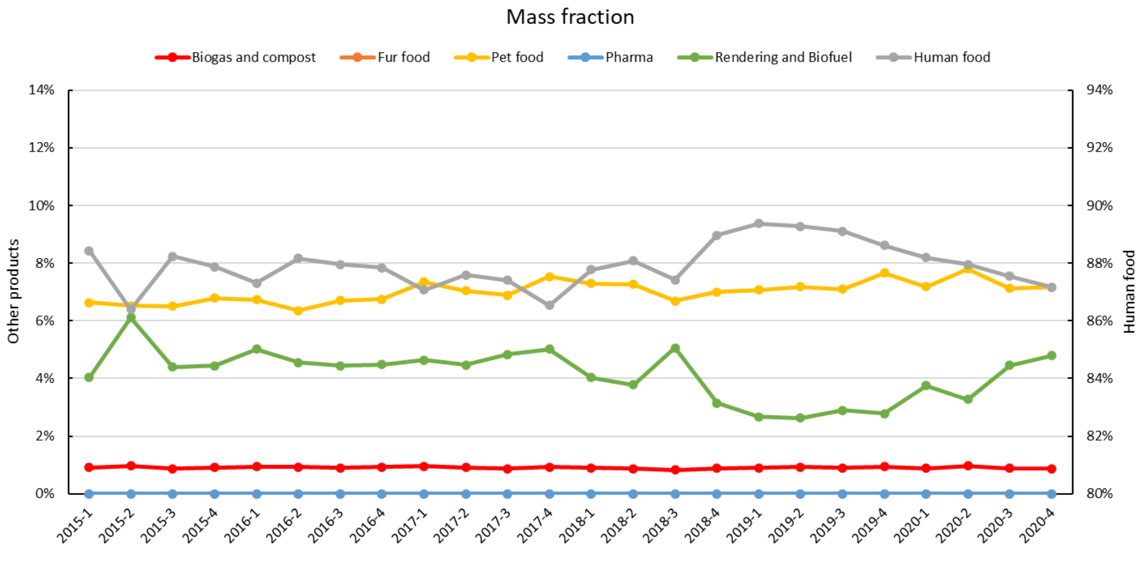

Figure 2 *Variation of mass fraction over 2015 and 2020 (quarterly basis) for pig slaughterhouse 1. The mass fraction for human food is presented on the right vertical axis, all others (inedible parts) are presented on the left vertical axis.*

Figure 3 shows the variation of the economic fraction. As it is seen, around 98% of total value belongs to human food products while the other products (including rendering and biofuel, biogas and compost, animal feed and pharma) had less than 2% contribution to the total value. As it is seen, the economic fractions were stable over the studied period. The reason for this is the high mass fraction for human consumption and a much higher price of human food products compared to by-products. The higher economic fraction of human food products covers the mass fraction fluctuation.

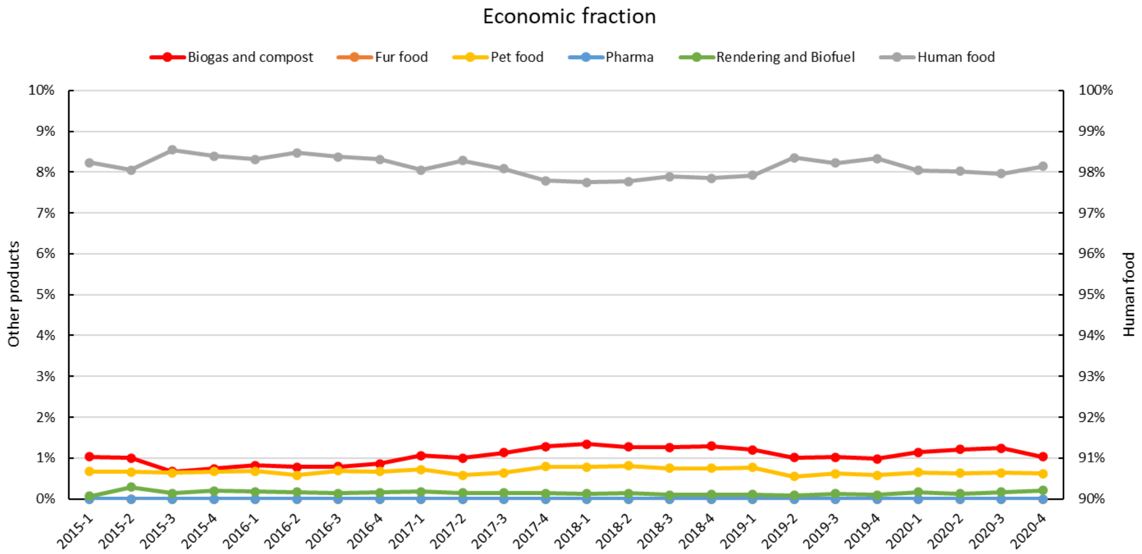

Figure 3 *Variation of economic fraction over 2015 and 2020 for pig slaughterhouse 1. The economic fraction for human food is presented on the right vertical axis, all others (inedible parts) are presented on the left vertical axis.*

Contrary to the pig slaughterhouse 1, a higher variation was seen in the mass fraction for the pig slaughterhouse 2 (Figure 4). Among the other products, the highest variation was seen for the rendering and biofuel group (5%) and followed by the fur food group (4%) and pet food (3%). The mass fraction of the human food group varied between 82% and 86%. On average around 84% of the slaughtered pig was utilized for human food purposes. Among the other products, rendering and biofuel (8%) and fur food (5%) had the highest contribution to the total mass of the slaughtered animal. The obtained results for the pig slaughterhouses showed the high (mass fraction between 84% and 88%) use of the slaughtered pig for human food purposes. Comparison of two pig slaughterhouses showed that access to the target markets plays a role in differences between the mass fractions of slaughterhouses, where in the pig slaughterhouse 2 due to access to the other markets more by-products are used for fur food and rendering and biofuel production purposes.

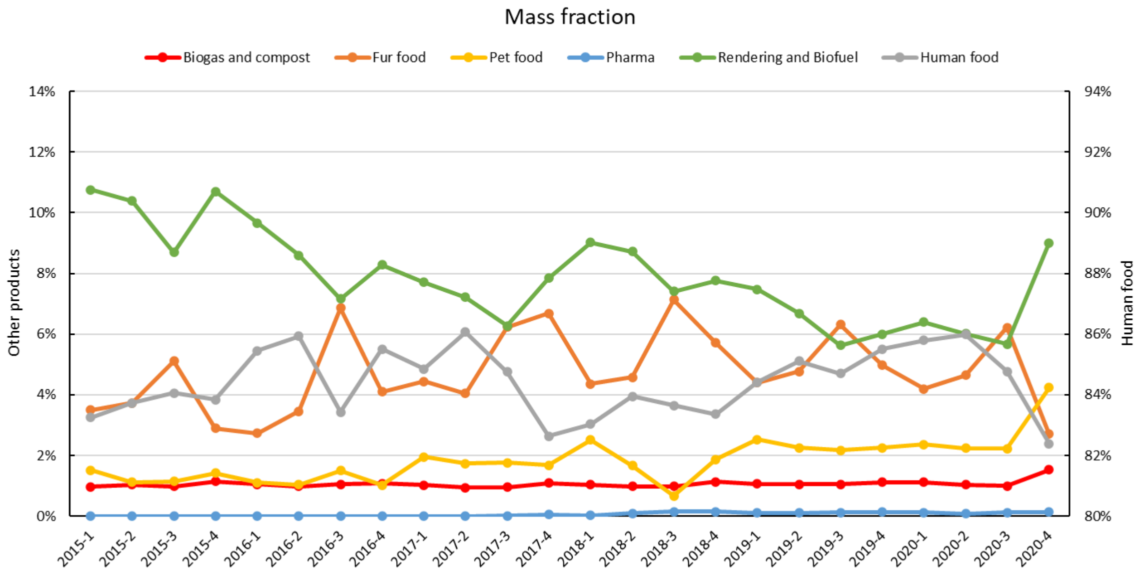

Figure 4 *Variation of mass fraction over 2015 and 2020 (quarterly basis) for pig slaughterhouse 2. The mass fraction for human food is presented on the right vertical axis, all others (inedible parts) are presented on the left vertical axis.*

For the economic fraction, an almost similar variation was seen for different types of the slaughtered animal parts (Figure 5). Due to the high mass fraction and economic value of human food products, this group had the highest economic fraction (98%) compared to the other product categories. The variation of the economic fraction for pig slaughterhouse 2 was almost similar to the pig slaughterhouse 1.

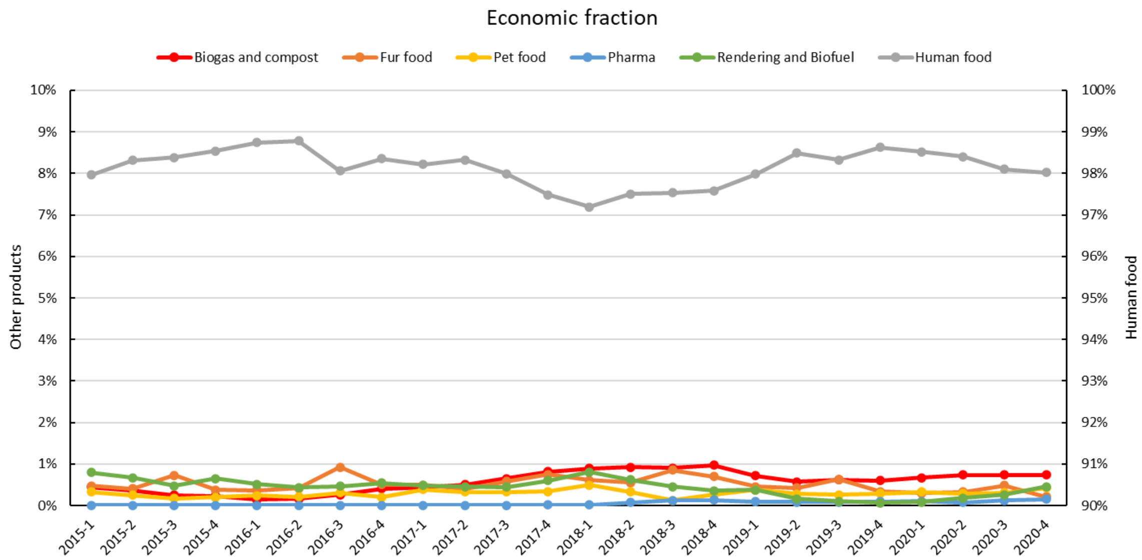

Figure 5 *Variation of economic fraction over 2015 and 2020 for pig slaughterhouse 2. The economic fraction for human food is presented on the right vertical axis, all others (inedible parts) are presented on the left vertical axis.*

4.2 Variation in mass and economic fractions in beef slaughterhouses

Figure 6 shows the variation of the mass fraction of different types of products in beef slaughterhouse 1 over 2016-2020. A large fraction (on average 60%) of the slaughtered animal is used for human food purposes. Rendering and biofuel (25%) was the main target use of beef by-products (inedible part), followed by pharma (12%) and pet food (3%). Evaluation of the technical fluctuation in a beef slaughterhouse showed that the mass fraction of human food products ranged between 58% and 62%. Among the other products (inedible parts), the highest variation was for pharma products (around 3%) and rendering and biofuel products (around 2%). For the rest of the by-products a stable situation was seen over 5 years.

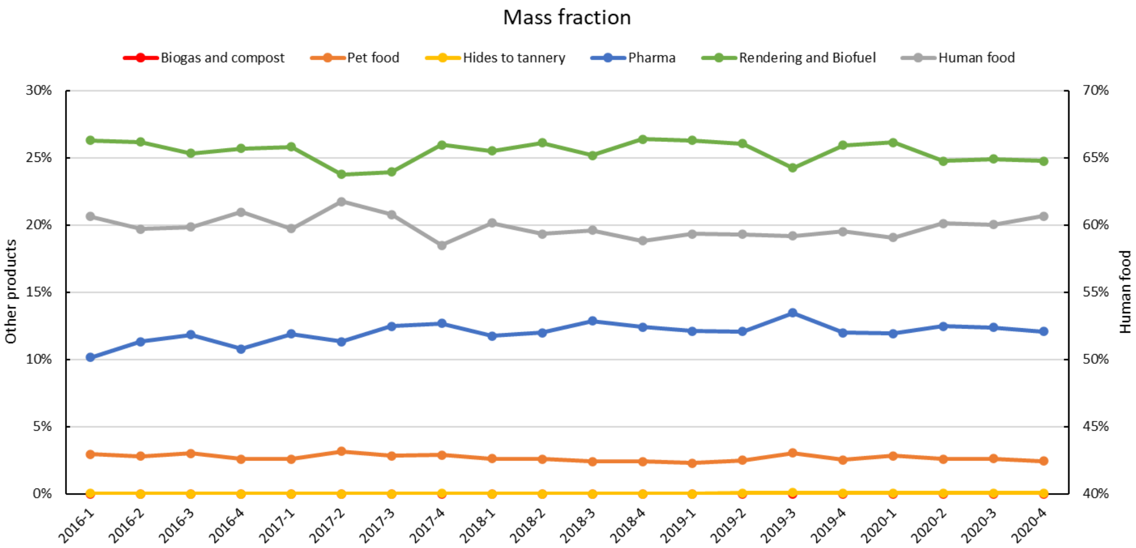

Figure 6 *Variation of mass fraction over 2016 and 2020 for beef slaughterhouse 1. The mass fraction for human food is presented on the right vertical axis, all others (inedible parts) are presented on the left vertical axis.*

The economic fraction was calculated for the beef slaughterhouse 1 and the obtained results showed that the human food contributed most (93%) to the total value of the slaughtered animal. Among other products, those used for rendering and biofuel production had the highest economic value (on average 5% of total value) and followed by pharma (economic fraction equal to 1.5%) and pet food products (economic fraction less than 1%). The economic fraction of human food products varied between 92% and 95% over 2016-2020. Studying the trend of the economic fraction showed that the human food product value declined after 2018 and since the mass fraction over this period was stable, it can be explained by the drop in the price of human food product. The highest variation among other products was for rendering and biofuel products (around 2%). In contrast to the human food products, the economic fraction of rendering and biofuel products raised after 2018 caused by the rising prices.

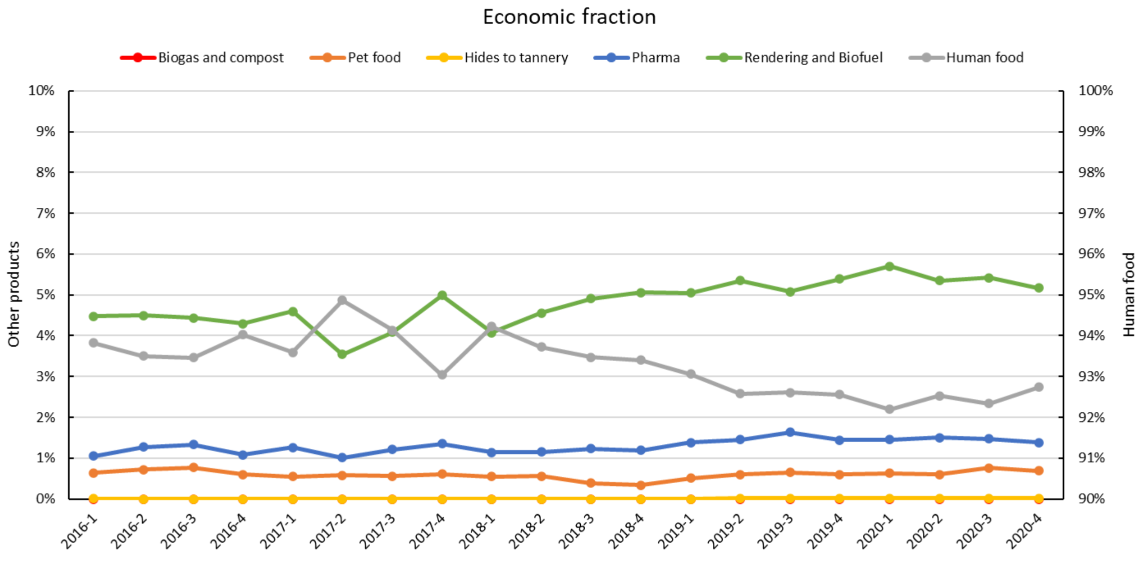

Figure 7 *Variation of economic fraction over 2016 and 2020 for beef slaughterhouse 1. The mass fraction for human food is presented on the right vertical axis, all others (inedible parts) are presented on the left vertical axis.*

Figure 8 shows the mass fraction fluctuation of beef slaughterhouse 2. As it is seen, human food accounts for 64% of total mass of the slaughtered animal, followed by biogas and compost (17%), pet food (13%), and hides and tannery (6%). As it is seen, based on the data provided by company, no changes were seen in the mass fraction of different products and by-products in beef slaughterhouse 2 over 2016-2020.

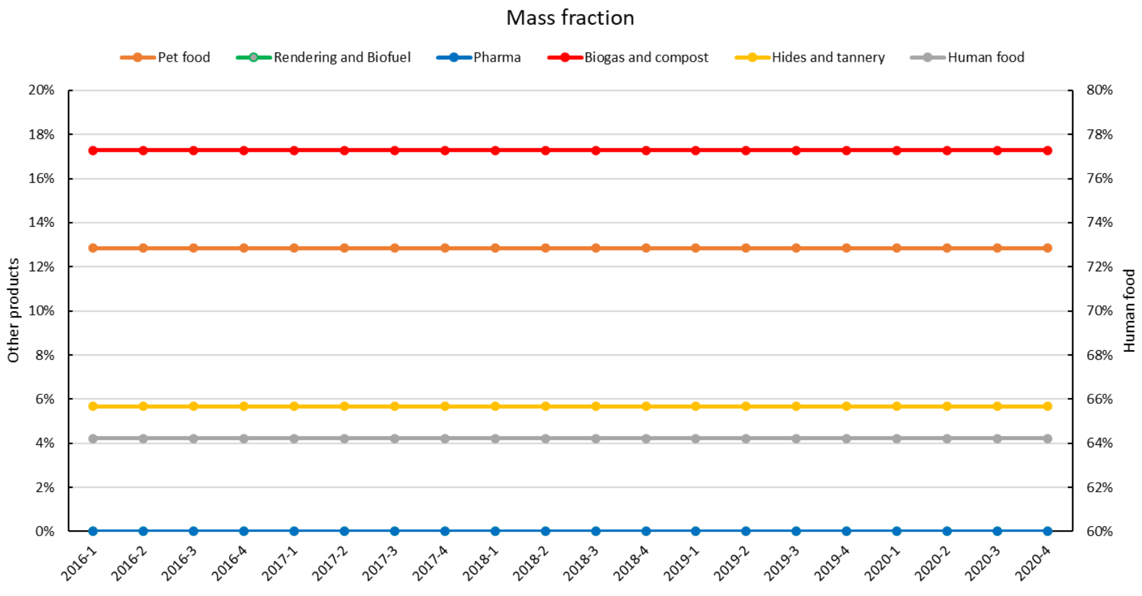

Figure 8 *Variation of mass fraction over 2016 and 2020 for beef slaughterhouse 2. The mass fraction for human food is presented on the right vertical axis, all others (inedible parts) are presented on the left vertical axis.*

The obtained results showed that human food contributed most (average economic fraction of 92%) to the total value of the slaughtered animal. The second valuable by-product was the hides and tannery group with the economic fraction equal to 7%. The rest of the by-products had an economic fraction less than 1%. The price fluctuation had a high impact on the fluctuation of the economic fraction of the human food and the hides and tannery groups. The economic fraction of human food ranged from 90% to 94% over 2016-2020. The variation of the economic fraction of hides and tannery group ranged between 5% and 10%.

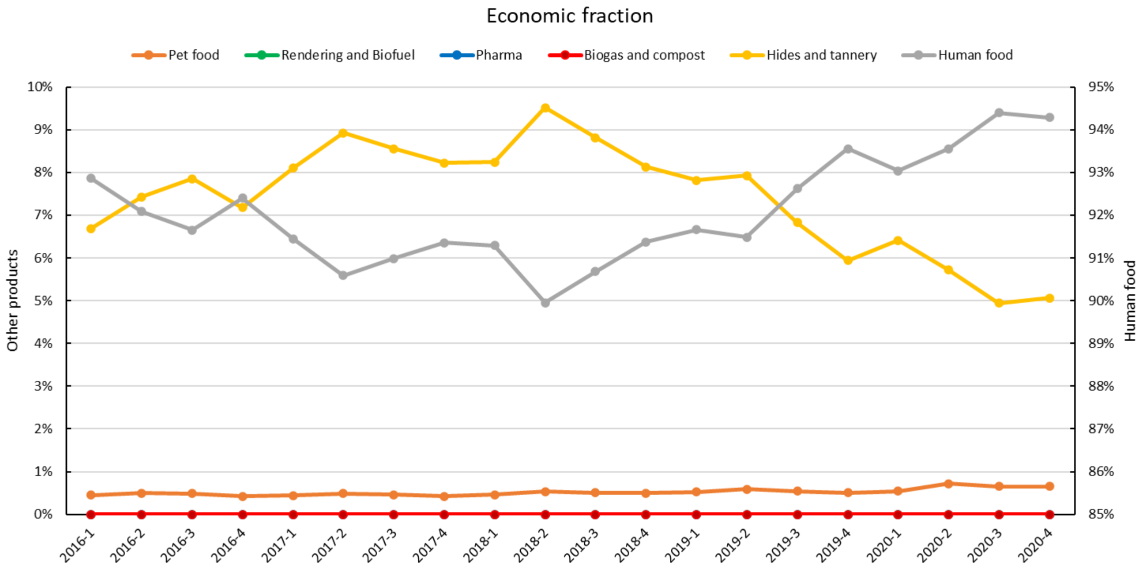

Figure 9 *Variation of economic fraction over 2016 and 2020 for beef slaughterhouse 2. The mass fraction for human food is presented on the right vertical axis, all others (inedible parts) are presented on the left vertical axis.*

In this chapter the current status of various slaughterhouses products was evaluated. For pig slaughterhouses, on average more than 80% of the slaughtered animal is used for human food purposes. Variation of the mass fraction for human food products underlined the improvements in slaughterhouses over the last years. Evaluation of the economic fraction in pig slaughterhouses showed that more than 98% of total value of the slaughtered animal belongs to the human food product. Compared to the mass fraction, because of high price of human food products, the economic fraction of human food products is significantly higher. The economic fraction was almost stable over a period between 2015 and 2020 for pig slaughterhouses. Despite of high price fluctuations of other products (inedible parts), the economic fraction could not reflect the existing variation due to high mass fraction and price of human food products compared to other products.

For beef, on average between 60-64% of the total mass of the slaughtered animal goes for human food purposes while the economic fraction of human food products in beef slaughterhouses was around 92%. A more stable situation was seen for mass fraction compared to economic fraction due to higher price fluctuation compared to the fluctuation of the mass fraction.

Due to the limitation in data availability, it was not possible to study the price fluctuation in a longer period and show the impact of higher price fluctuation on the economic fraction of different (by)products. For some by-products such as Cat. 3 by-products less price fluctuation is seen for the studied period compared to period between 2000-2021.

5 Comparison of small- and large-scale slaughterhouses

To gain insight in the variability at slaughterhouses and find out whether the allocation factors (mass and economic fractions) can show the existing differences among different slaughterhouses, we compared the small- and large-scale slaughterhouses. Slaughterhouses have been categorised on their annual production and also on their access to international markets. As it has been discussed in *Chapter 3* there is no specific approach to classify the slaughterhouses. Therefore, based on our observations, the studied slaughterhouses were categorized to small- and large-scale ones. Small slaughterhouses are the ones with lower level of yearly production and limited access to the markets outside the country and almost all of their products are sold to the domestic markets. The comparison was carried out for both pig and beef slaughterhouses.

5.1 Comparison of small and large-scale pig slaughterhouses

For comparison of pig slaughterhouses, two large-scale slaughterhouses were compared with one small-scale unit. To make the results comparable, we classified the slaughtered animal products to two main categories namely the edible (human food) and inedible (other products) categories. To show the variation over time, the allocation fractions have been presented over 2015-2020. Table 1 shows the comparison of the mass fraction between small- and large-scale slaughterhouses. A higher variation was seen for the mass fraction in small-scale slaughterhouse compared to the large-scale units. The results showed a low level of changes for the mass fraction in the large slaughterhouses. A high potential for improvement in small slaughterhouse was seen, where this unit can increase the fraction of human food products by using more by-products for human food purposes. This was shown in Table 1, where the fraction of human food in small scale slaughterhouses increased over the period 2015-2020.

Table 1 *Comparison of mass fractions of small- and large-scale pig slaughterhouses.*

	2015	2016	2017	2018	2019	2020	Average
Small-scale							
Human food	69.8%	70.9%	71.5%	72.0%	79.2%	84.3%	74.6%
Other products	30.2%	29.1%	28.5%	28.0%	20.8%	15.7%	25.4%
Large-scale 1							
Human food	83.7%	85.1%	84.6%	83.5%	84.9%	84.7%	84.4%
Other products	16.3%	14.9%	15.4%	16.5%	15.1%	15.3%	15.6%
Large-scale 2							
Human food	87.7%	87.8%	87.1%	88.1%	89.1%	87.7%	87.9%
Other products	12.3%	12.2%	12.9%	11.9%	10.9%	12.3%	12.1%

Comparison of the economic fraction of small- and large-scale pig slaughterhouses showed no substantial difference between slaughterhouses (Table 2). Human food products contributed most (between 97% and 98%) to the total economic value. As it is seen, the variation of the economic fraction was low in both small- and large-scale slaughterhouses. This is due to the relatively high prices for the human food fraction and the very low prices for the other products (or even no price at all), which mathematically already gives high economic fractions in the case of relatively low human food fractions.

Table 2 *Comparison of economic fractions of small- and large-scale pig slaughterhouses.*

	2015	2016	2017	2018	2019	2020	Average
Small-scale							
Human food	96.5%	97.2%	97.3%	97.0%	97.2%	97.2%	97.1%
Other products	3.5%	2.8%	2.7%	3.0%	2.8%	2.8%	2.9%
Large-scale 1							
Human food	98.3%	98.5%	98.0%	97.5%	98.4%	98.3%	98.1%
Other products	1.7%	1.5%	2.0%	2.5%	1.6%	1.7%	1.9%
Large-scale 2							
Human food	98.3%	98.4%	98.0%	97.8%	98.2%	98.0%	98.1%
Other products	1.7%	1.6%	2.0%	2.2%	1.8%	2.0%	1.9%

5.2 Comparison of small and large-scale beef slaughterhouses

The results of comparing the small- and large-scale beef slaughterhouses are presented in Table 3. As it is presented, for human food products, the average mass fraction ranged from 60% to 64%. The provided data showed no substantial variation over 2016-2020. One of the larger-scale slaughterhouses had a larger fraction of human food products than the small-scale slaughterhouse while for the other one, no difference with the small-scale could be seen.

Table 3 *Comparison of mass fractions of small- and large-scale beef slaughterhouses.*

	2016	2017	2018	2019	2020	Average
Small-scale						
Human food	60.7%	60.7%	60.7%	60.7%	60.7%	60.7%
Other products	39.3%	39.3%	39.3%	39.3%	39.3%	39.3%
Large-scale 1						
Human food	64.2%	64.2%	64.2%	64.2%	64.2%	64.2%
Other products	35.8%	35.8%	35.8%	35.8%	35.8%	35.8%
Large-scale 2						
Human food	60.3%	60.2%	59.5%	59.3%	60.0%	59.8%
Other products	39.7%	39.8%	40.5%	40.7%	40.0%	40.2%

The results of the economic fraction analysis for the small- and large-scale beef slaughterhouses showed the higher economic fraction for human food products for the small-scale slaughterhouse compared to the large-scale slaughterhouses. These results revealed that the small-scale beef slaughterhouse had a better market compared to the large-scale slaughterhouses. Although there were some differences between the economic fractions of small- and large-scale slaughterhouses, the differences were not substantial.

Table 4 *Comparison of economic fractions of small- and large-scale beef slaughterhouses.*

	2016	2017	2018	2019	2020	Average
Small-scale						
Human food	95.3%	95.1%	96.6%	97.4%	97.8%	95.3%
Other products	4.7%	4.9%	3.4%	2.6%	2.2%	4.7%
Large-scale 1						
Human food	92.3%	91.1%	90.8%	92.3%	93.8%	92.4%
Other products	7.8%	8.9%	9.2%	7.7%	6.2%	7.6%
Large-scale 2						
Human food	93.7%	93.9%	93.7%	92.7%	92.4%	93.3%
Other products	6.3%	6.1%	6.3%	7.3%	7.6%	6.7%

To sum it up, based on the obtained results, it was revealed that there are differences between the small- and large-scale slaughterhouses regarding their performance. The difference was higher among pig slaughterhouses compared to the beef slaughterhouses. Mass fractions could show the differences in performance of slaughterhouses however economic fractions could not reflect the differences. The higher prices of human food products covered the changes in mass fractions.

6 Historic developments in mass fractions of edible products

One of the important issues which should be considered when selecting the appropriate allocation approach, is its capability in showing the technical improvement of slaughterhouses over the years. As mentioned in the introduction chapter, increasing the fraction of human food products and at the same time reducing the fraction of wastes by using them in production of other products with added value, is considered as an environmental improvement. To assess whether the technical improvement in slaughterhouses exists, we compared the share of different categories for two different years (2005 and 2015). Due to a limitation in availability of price data, just the historic change of mass fraction was studied. Due to same issue, the evaluation was limited to one pig and one beef slaughterhouse. In the next paragraphs the results of comparisons for both pig and beef slaughterhouses are presented.

6.1 Historic developments in a pig slaughterhouse

As it is presented in Table 5, over a period of 10 years, the fraction of human food products increased (around 5%) and the fraction of by-products used for rendering and biofuel production reduced by 7%. The fraction of fur food products has increased (2%) and for the rest of products, no substantial change was seen. A substantial improvement in the human edible fraction was occurred over time in the studied pig slaughterhouse. This is important in terms of environmental aspects where more by-products are being used for human purposes and for feeding animals compared to 10 years ago.

Table 5 *Comparison of mass fractions at time interval of 10 year in a pig slaughterhouse.*

Group of products	2005	2015
Biogas and compost	1.4%	1.3%
Fur food	0.7%	3.1%
Pet food	3.5%	4.1%
Human food	79.5%	83.8%
Pharma	0.2%	0.2%
Rendering and Biofuel	14.7%	7.5%

6.2 Historic developments in a beef slaughterhouse

Table 6 presents the mass fraction of different (by)products including the waste for incineration. Results showed that over a period of 10 years, the studied slaughterhouse increased the human edible fraction and the fraction for pharma and leather, mainly at the expense of the fraction of by-products for incineration. This technical (and economic) improvement can be considered as an environmental improvement. Compared to the year 2005, 1.6% of the total mass of slaughtered animal was used as pharma products in 2015. Obtained results showed a more than 3% increase in the fraction of human food products over a period of 10 years in a beef slaughterhouse. Due to a limitation on data availability, it was possible to study just one of the beef slaughterhouses. However, personal communication with companies revealed that since 2005, some improvements occurred in terms of using more by-products in the production of various products which replace the synthetic products. Moreover, the fraction of human food products increased over a period of 10 years.

Table 6 *Comparison of mass fractions at time interval of 10 year in a beef slaughterhouse.*

Group of products	2005	2015
Human food	61.1%	64.3%
Pet food	7.6%	7.8%
Rendering and Biofuel	0.0%	0.0%
Pharma	0.0%	1.6%
Biogas and compost	7.1%	7.1%
Leather	7.2%	7.9%
Incineration	17.0%	11.2%

To summarize, as it has been shown in this section, slaughterhouses improved their performance by increasing the fraction of human food products over the period between 2005 and 2015. However, the fixed allocation factors suggested by the JRC PEF cannot show the technical improvements in slaughterhouses. In the next chapters the application of both mass and economic fractions and also the allocation ratio (as suggested by the JRC PEF) will be discussed extensively.

7 Comparison of JRC PEF and actual situation

In this section, the difference between the available mass and economic fractions (as suggested by the JRC PEF guideline) is compared with the actual situation of slaughterhouses to see whether there is a difference between the JRC PEF figures and the actual situation. Comparison was done for both pig and beef slaughterhouses.

7.1 Comparison of JRC PEF and the actual situation in pig slaughterhouse

As it has been discussed in *Chapter 2*, the JRC PEF suggests fixed allocation factors for different groups of (by)products. Thus, all slaughterhouses should apply these allocation factors to partitioning the upstream emissions to different (by)products. To gain insight in the difference between allocation factors based on the fixed JRC PEF approach and the actual situation, we compared the fixed mass and economic fractions and the allocation factor with the average values of slaughterhouses for a six-year period (2015-2020). This comparison was carried out for two pig slaughterhouses (which could meet the data requirement of this evaluation) which are located in two different European countries. According to the JRC PEF guideline, the allocation for slaughtered pigs is done for human food products and Cat. 3 by-products which have an economic value and for the rest of the by-products (which are considered as waste) no allocation is applied. Given that Cat. 2 slaughter by-products in some slaughterhouses have an economic value, we considered it in our calculations. As it is shown in Table 7, for the human food product group there is a difference (7% units) between the JRC PEF mass fraction and the actual situation. This difference shows that, a higher fraction of the slaughtered pigs is used for human food purposes in the actual situation. In contrast to the mass fraction, there was no substantial difference between the economic fraction recommended by the JRC PEF and the actual situation, especially when aggregating the human food category (a+b+c). Comparison of allocation ratios showed that the JRC PEF suggests a higher value for the human food group than the actual situation. This is because of higher mass fraction of fresh meat and edible offal group in the actual situation. Moreover, the JRC PEF does not consider an allocation ratio for Cat. 2 slaughter by-products while in practice, it can be considered for allocation due to its economic value.

Table 7 *Comparison of the JRC PEF method and the actual situation for pig slaughterhouse 1.*

	Mass fraction		**Economic fraction**		**Allocation ratio**	
	JRC PEF	Actual situation	JRC PEF	Actual situation	JRC PEF	Actual situation
a+b+c	81	87.93	99.23	98.13	1.23	1.12
d	19	11.17	0.77	0.82	0.04	0.07
e	0.0	0.0	0.0	0.0		
f		0.91		1.05		1.16

a) Fresh meat and edible offal

b) Food grade bones

c) Food grade fat

d) Cat. 3 slaughter by-products

e) Hides and skins (categorized in cat. 3 products)

f) Cat. 2 slaughter by-products

Comparison of the JRC PEF method and the actual situation for the pig slaughterhouse 2 showed a small difference among the mass fractions. In total, a 3.4% unit higher fraction was used as edible food, while a 1.1% unit fraction was used for energy production. Similar economic fractions were calculated for both scenarios. The allocation ratios (economic fraction divided by mass fraction) for the human food group based on the JRC PEF method and the actual situation were 1.23 and 1.16, respectively. Similar to the pig slaughterhouse 1, Cat. 2 slaughter by-products had an economic value which based on the JRC PEF guideline should not be considered in allocation calculations.

Table 8 *Comparison of the JRC PEF method and the actual situation for the pig slaughterhouse 2.*

	Mass fraction		**Economic fraction**		**Allocation ratio**	
	JRC PEF	Actual situation	JRC PEF	Actual situation	JRC PEF	Actual situation
a+b+c	81	84.43	99.23	98.14	1.23	1.16
d	19	14.51	0.77	1.29	0.04	0.09
e	0.0	0.0	0.0	0.0		
f		1.06		0.57		0.54

a) Fresh meat and edible offal

b) Food grade bones

c) Food grade fat

d) Cat. 3 slaughter by-products

e) Hides and skins (categorized in cat. 3 products)

f) Cat. 2 slaughter by-products

Based on the results obtained by comparing the JRC PEF method and the actual situation it can be concluded that for mass fraction the differences ranged from 3% to 8% units for the human products and Cat. 3 slaughter by-products. These differences might look small but are relevant. The fraction of waste is considerably reduced. The economic fractions show the opposite development, despite the higher mass fraction in reality, the economic fraction is slightly smaller, especially when aggregating the human food category. But the relatively high prices for the edible fractions (a+b+c), compared to the others lead to very high economic fractions anyway, so small changes are expected.

7.2 Comparison of the JRC PEF method and the actual situation in beef slaughterhouse

In this section the fixed valuses for mass and economic fraction of different products recommended by the JRC PEF are compared with the actual situation of a beef slaughterhouse. According to the JRC PEF, around 64% of the slaughtered animal is used for the human food and 22% is Cat. 1 or 2 by-products. Hides and skins and Cat. 3 by-products accounted for 7% of total weight of the slaughtered animal (Table 9). Despite a small difference between the mass fraction of human food products reported by the JRC PEF (64%) and the actual situation (60%), for the other categories larger differences in the mass fractions were reported between the JRC PEF method and the actual situation. With respect to the economic fraction, 2% difference was seen between the JRC PEF value and the actual situation for the human food products. The difference was higher for the other products (inedible parts). The difference between the JRC PEF figures and the actual situation shows that although for the edible part almost similar values (difference was less than 5%) were reported, for the inedible products higher difference was seen. It should be noted that in the case of beef, in the actual situation smaller mass fractions are reported compared to the JRC PEF values. In the pig slaughterhouses the opposite was the case.

Table 9 *Comparison of the JRC PEF method and the actual situation for the beef slaughterhouse 1.*

	Mass fraction		Economic fraction		Allocation ratio	
	JRC PEF	Actual situation	JRC PEF	Actual situation	JRC PEF	Actual situation
a+b+c	64	59.85	95.7	93.29	1.50	1.56
d	7	40.13	0.8	6.70	0.11	0.17
e	7	0.02	3.5	0.01	0.51	0.24
f	22	0.00	0.0	0.00	0.00	0.00

a) Fresh meat and edible offal

b) Food grade bones

c) Food grade fat

d) Cat. 3 slaughter by-products

e) Hides and skins (categorized in Cat. 3 products)

f) Cat. 1 or 2 slaughter by-products

Table 10 illustrates how much the JRC PEF fixed mass and economic fractions fit the actual situation based on the data for beef slaughterhouse 2. Compared to the beef slaughterhouse 1, the JRC PEF mass fraction for human food products fitted more to the actual situation in slaughterhouse 2. However, substantial difference was seen for the Cat. 3 slaughter by-products and Cat. 1 or 2 slaughter by-products. Comparison of economic fractions of the JRC PEF method and the actual situation showed some small differences. Also, in the case of beef, maximum differences between the actual situation and the JRC PEF are found to be approximately 5% units, which is in the same range as for pigs. For the other categories, the differences between the JRC PEF and the actual situation are large.

Table 10 *Comparison of the JRC PEF method and the actual situation for the beef slaughterhouse 2.*

	Mass fraction		Economic fraction		Allocation ratio	
	JRC PEF	Actual situation	JRC PEF	Actual situation	JRC PEF	Actual situation
a+b+c	64	64.2	95.7	92.6	1.50	1.44
d	7	13.6	0.8	0.5	0.11	0.04
e	7	5.7	3.5	6.8	0.51	1.21
f	22	17.3	0.0	0.03	0.00	0.002

a) Fresh meat and edible offal

b) Food grade bones

c) Food grade fat

d) Cat. 3 slaughter by-products

e) Hides and skins (categorized in Cat. 3 products)

f) Cat. 1 or 2 slaughter by-products

In summary, by comparing the mass and economic fractions of the JRC PEF guideline and real data from the slaughterhouses the conclusion can be drawn that the fixed JRC PEF values do not reflect the actual situation of these slaughterhouses. Moreover, as it was discussed, splitting the human food products to three sub-categories including fresh meat and edible offal, food grade bones and food grade fat is not feasible in practice. Furthermore, based on the JRC PEF method no allocation factor is assigned for Cat. 1 and 2 by-products due to the lack of an economic value. However, in practice some of by-products in these categories can have an economic value. It will be discussed further in the next *Chapter*.

8 Discussion

In this chapter and based on the obtained results mass and economic allocation approaches are evaluated. We start with the comparison between the fixed mass and economic fractions and the related allocation ratios of the JRC PEF method and the results of the slaughterhouses. The pros and cons of both mass and economic allocation are discussed. Ultimately, the robustness, flexibility, and ability to create incentives of each method are evaluated to provide a more holistic overview about approaches.

8.1 Improvements in the slaughter process

Changes over time

The first evaluation was about the current status of various slaughterhouses products. For pig, on average more than 80% of the slaughtered animal is used for human food purposes. After the human food category, feed production (pet food and fur food) had the highest fraction of the slaughtered animal and followed by rendering and biofuel production and biogas production. The mass fraction fluctuation of human food products was around 5% in a period of 2015-2020. The variation of mass fraction for human food products underlined the improvements in slaughterhouses over the last years. By applying newer technology and also accessing new markets (in East Asia) a higher fraction of the slaughtered animal will likely be used for human food purposes compared to 2005. However, in recent years because of lockdown conditions (due to Covid-19), a small reduction in the mass fraction of human food products was seen (based on personal communications with companies). Since 2015 compared to 2005, some improvements can be reported due to the smaller fraction of total mass uses for rendering. These improvements in the technical performance of enterprises and the resulting allocation factors and the footprints need to be reflected by the allocation approach. Compared to pig, a lower fraction (65%) of the total mass of slaughtered cattle is used for human food purposes. The obtained results also showed that for the other products (inedible parts) the mass fraction differs from company to company. This difference was higher among the beef slaughterhouses compared to pig slaughterhouses.

Small-scale and large-scale slaughterhouses

Due to the limited availability of data, we have not been able to study the effect of small-scale versus large-scale slaughterhouses in depth. However, the limited results showed some differences between slaughterhouses. The differences between small- and large-scale pig slaughterhouses were higher than the differences in small- and large-scale beef slaughterhouses in terms of the mass fraction of products. The availability of and access to a market (specifically international market) influence the share of edible by-products in the total mass of the slaughtered animal. This was especially seen in pig slaughterhouses where the large-scale ones reported higher mass fractions for human food products on average. However, the results of beef slaughterhouses did not completely support this argue due to diverse results obtained. A potential to increase the mass fraction of human food products was seen in small-scale slaughterhouses showing technical (and hence environmental) improvements is important for small-scale slaughterhouses as well as for large-scale ones. To incentive slaughterhouses to improve their performance in higher edible fractions, mass fractions can be applied. The economic fraction could not show the existing difference among the slaughterhouses.

Fixed allocation factors by JRC PEF

By comparing the mass and economic fractions and also allocation ratios of the JRC PEF guideline and the actual situation in four slaughterhouses, it was revealed that the JRC PEF fixed mass fraction is not aligned with the actual situation. This difference can be due to variation among slaughterhouses and also environmental improvements in the slaughterhouses over years which resulted in a higher mass fraction of human food products. In contrast with the mass fraction, the suggested economic fraction by the JRC PEF is more aligned with the actual situation which is because of high prices for human edible fractions. One of the important differences between the JRC PEF method and the actual situation was how the human food products are categorized. The JRC PEF splits the human food products to three sub-categories including fresh meat and edible offal, food grade bones and food grade fat. Based on our observation and experience it is very difficult for the slaughterhouses to provide data for sub-categories suggested by JRC PEF. Therefore, we believe that it is not realistic to split the human food product to different sub-categories. The necessity of the proposed division needs to be discussed further. In addition to splitting the human food products to sub-categories, there is a difference between the definition of the Cat. 2 slaughter by-products in the JRC PEF method and the actual situation. The JRC PEF considers Cat. 2 by-products as waste material without economic value. As a consequence, no allocation factor should be applied for this category of by-product. Due to the fact that in the actual situation this by-product has an economic value we have taken it into consideration. This assumption also needs to be discussed further in order to prevent misunderstanding or misinterpretations.

Based on our observation, in addition to waste, some by-products have negative or zero economic value (price) at the slaughterhouse gate. Based on the JRC PEF guideline, wastes and by-products without economic value at slaughterhouse gate should not be considered for allocation, even if they are being used for further processing in production of a good (e.g., biogas). Therefore, application of economic allocation depends on having market prices for all by-products at the slaughterhouse gate. Due to the fact that waste and by-products have a potential to be used in the production of other products, we believe that it is essential to consider them for allocation. Based on ISO 14044, the economic value of by-product at slaughterhouse gate can be estimated by subtracting the cost of further processing, packaging or transportation from the eventual market price of a final product (ISO, 2019).

8.2 Pros and cons of mass and economic allocation

Both mass and economic allocation approaches have their own advantages and disadvantages. Based on the results obtained in this study, in this section we list various advantages and disadvantages of both methods. Before discussing the pros and cons, a typical aspect of the economic allocation has to be studied in detail.

Economic allocation covering differences over time and between scales
Applying new technologies to bringing more added value to the by-products and finding new markets for using by-products for human food purposes play an important role in improving the environmental performance of slaughterhouses. It is important that the potential for further improvements in environmental performance of enterprises be reflected by the allocation approach. These improvements over time and among slaughterhouses can be reflected using the mass fraction.

Economic allocation is a combination of mass fraction and (by)product prices. This type of allocation is also applied in crop processing and as a consequence for the emissions in the feed chain (JRC PEF feed). There are two important differences between the food and dairy processing industry on the one hand and the slaughter sector on the other:

- The food and dairy industry produce hardly waste or no waste. Waste fractions in the slaughter process are in the range of 5-10% for pigs and 25% for beef.
- The differences in prices between the main and by products are relatively small (within a factor 2 or 3) in the food and dairy processing industry. In the slaughter process, by-products and waste have very low prices (or no price) in comparison to the main product, the edible meat. The ratio lies between 1 to 10 and 1 to 20.

Especially the latter has a very large influence on the relationship between mass and economic fractions, as can be seen in Figure 10. In this calculation, with an edible fraction of 40%, already 93% of the economic value is realized. With 60% edible meat, this goes up to 97%. It illustrates that large changes in edible fractions are hardly reflected in changes in economic fractions, due to the hyperbolic relationship between the two. In the range of our study, improvements from 70 to 84 edible fraction have been seen in small-scale slaughterhouses (*Chapter 5*), which only led to changes from 96 to 97% of the economic fraction. This is also clearly illustrated in Figure 10. This implies that relevant and significant improvements in the slaughter process are much less visible by the application of economic allocation. Hence, the economic fraction covers the technical changes over time and differences between slaughterhouses. Therefore, it cannot reflect the environmental improvements over time.

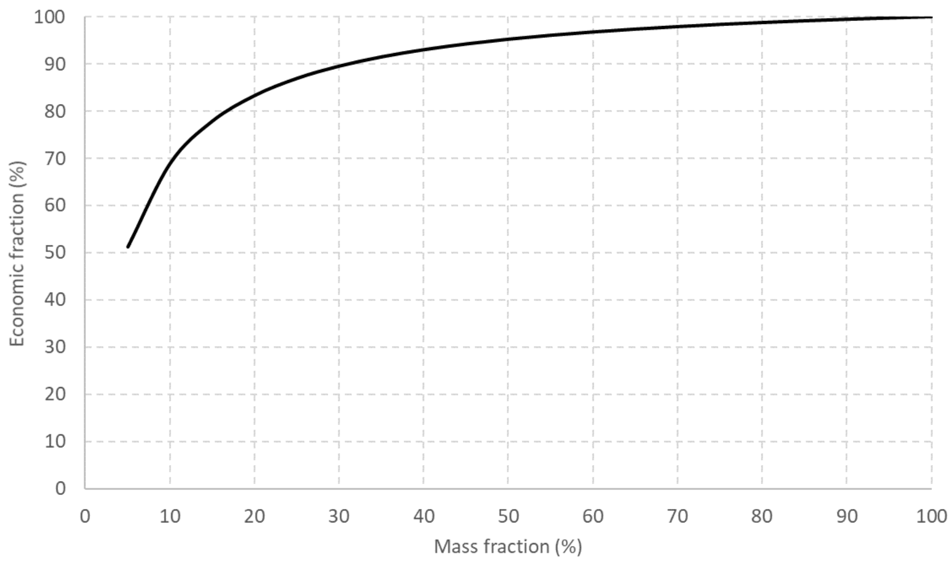

Figure 10 *The relationship between mass and economic fraction of the main product (edible meat) in the case of a price fraction between edible and non-edible of 20 to 1.*

The use of flexible mass fraction

As it has been discussed, one of the weaknesses of the JRC PEF method is its inability to show the improvements of slaughterhouses. Fixed mass and economic fractions cannot show the differences between slaughterhouses and the changes in slaughterhouses over time. The changes of the mass fractions show the performance of slaughterhouses, while the price changes reflect the market fluctuation. To explore whether the flexible mass fraction can be incorporated in the JRC PEF method, we defined different scenarios based on the results of the slaughterhouses (as shown in Table 11) and assessed them. To exclude the impact of the price fluctuation on allocation ratios, fixed prices (extracted from the JRC PEF) were assumed for (by)products in all scenarios. As it is shown, from *Scenario 1* to *Scenario 4*, the mass fraction of human edible products (a+b+c) increases from 0.64 to 0.69. Parallel to the increase of the human edible fraction, the fraction of d (Cat. 3 slaughter by-products) and f (Cat 1 and 2 by products) decreases. For *Scenario 5*, where no further increase happens for the human edible fraction compared to *Scenario 1*, but a big portion of by-product "f" has been treated in the wrong way and is considered as waste, shifts to category "d" (Cat. 3 slaughter by-products). The by-product "f" does not have any economic value while by-product "d" has. Results of this assessment showed that increasing the human edible fraction (a+b+c) of the slaughtered animal (from *Scenario 1* to *Scenario 4*) results in a lower allocation ratio for edible category. The allocation ratios for the other groups are lower as well. These results show that flexible mass fraction can reflect the environmental improvements of slaughterhouses. Comparison of *Scenario 4* and *Scenario 5* where a shift takes place from by-product without value (Cat. 1 or 2 slaughter by-products) to a valued by-product (Cat. 3 slaughter by-products), shows that using this approach, any change in mass fraction of by-products also slightly affects the allocation ratios of human edible category. This effect is somewhat stronger in a case hides and skins fraction increase. So, the efforts to create the maximum added value of slaughterhouses by maximizing the mass fractions with the highest price, will affect the allocation ratios and hence will reflect environmental improvements.

Moreover, as it is seen no changes occurred in the mass fraction of hides and skins (categorized in Cat. 3 products) from *Scenario 1* to *4*, however the related allocation ratio reduced. Therefore, based on this scenario evaluation, applying flexible mass fractions in the JRC PEF method can reflect technical improvements of slaughterhouses however, it is shown that the allocation ratio for the edible products is not only affected by the fraction of edible products, but also is affected by the changes in mass fraction of by-products.

Table 11 *Mass, mass fraction, price, economic fraction and allocation ratio for five scenarios in a beef slaughterhouse.*

Item	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
	Mass (kg)				
a+b+c	384	394	404	414	384
d	42	37	32	27	82
e	42	42	42	42	42
f	132	127	122	117	92
Total	600	600	600	600	600
	Mass fraction				
a+b+c	0.64	0.66	0.67	0.69	0.64
d	0.07	0.06	0.05	0.05	0.14
e	0.07	0.07	0.07	0.07	0.07
f	0.22	0.21	0.20	0.20	0.15
Total	1	1	1	1	1
	Price (€/kg)				
a+b+c	3	3	3	3	3
d	0.18	0.18	0.18	0.18	0.18
e	0.8	0.8	0.8	0.8	0.8
f	0	0	0	0	0
	Economic fraction				
a+b+c	0.97	0.97	0.97	0.97	0.96
d	0.01	0.01	0.01	0.01	0.01
e	0.03	0.03	0.03	0.03	0.03
f	0.00	0.00	0.00	0.00	0.00
Total	1	1	1	1	1
	Allocation ratio				
a+b+c	1.51	1.47	1.44	1.41	1.50
d	0.09	0.09	0.09	0.08	0.09
e	0.40	0.39	0.38	0.37	0.40
f	0.00	0.00	0.00	0.00	0.00

a) Fresh meat and edible offal

b) Food grade bones

c) Food grade fat

d) Cat. 3 slaughter by-products

e) Hides and skins (categorized in Cat. 3 products)

f) Cat. 1 or 2 slaughter by-products

8.2.1 Mass allocation

Mass allocation uses data which are robust and relatively stable over time and easily accessible or available. Any change in mass fraction is caused by changes in the operation of a processing unit. This approach is very simple and easy to apply. It reflects the physical and natural relationships. In this approach the denominator depends directly on the products and directly quantifies the improvement in increasing the edible fraction or other useful products as fur and pet food. Comparing different units in different regions with different economic markets can be possible using mass allocation. Also, when there is no economic market in a region, mass allocation is the feasible approach.

The disadvantage of applying mass allocation is the fact that no distinction is made between the different parts, although the names of the various products already clearly show how the products will be used. Distinction can be made on the basis of physical qualities like the nutritional value. But attempts to distinguish products on the basis of their nutritional value have not yet yielded a satisfactory result. The issue with the distinction between (co)products is the act that consumer's preferences play a very strong role.

This implies that technical improvements, leading to a higher edible fraction and which can be considered as an environmental improvement as well, will not affect the carbon footprint of the edible meat, because all products and co-products are treated equal. Compared to the situation where the carbon footprint is mainly partitioned to the edible products (i.e., the economic allocation) there is no "reward" in the form of a carbon footprint per unit edible meat. This reduced carbon footprint due to allocation could act as an incentive.

8.2.2 Economic allocation

Given that economic allocation is adapted to multiple, complex functional attributes among products with different origins, functions and uses, it would be an advantage for this approach. It reflects the socio-economic attributes, which is more preferable compared to the mass allocation where no distinction is made between high and low preferred products. It is more rational for systems in which large quantities of by-products with relatively low economic value are produced. Both economic and environmental aspects should play an important role since they influence the consumers preferences and choices. Allocation should not only show the physical relationships but also social orientations.

As a disadvantage, economic allocation is not stable due to price fluctuations over time (to increase the stability, economic value needs to be averaged for some years), markets and among regions. Price fluctuation might cover the technical fluctuation; therefore, the environmental performance of slaughterhouses might be covered by high prices of the edible fraction as has been shown before. In some cases where there is no definite economic market or lack of data for the co-product, economic allocation is not applicable. In some cases, it is in contrast to the purpose of using LCA. The economic allocation can also be affected by external factors as government policies, social and economic tensions. As economic allocation is hiding improvements in increasing edible fractions or the improved use of waste products (up to co-products), albeit not on purpose, it could be considered as a lack of incentive to the slaughterhouse companies to reduce the environmental impacts of by-products with a low economic value. The economic results might drive slaughterhouse to improve their performance, but it is not essentially reflecting the environmental performance. In some cases, slaughterhouses can hide their environmental performance by selling their by-products with higher prices.

On the other hand, increasing the edible fraction, or improved use of co-products and waste (including higher prices) will be reflected in the carbon footprint of edible meat, as is shown by the lower allocation ratios to edible meat in Table 7.

Another aspect of the economic allocation is the availability of prices. Companies are not willing to apply economic allocation as it is partly showing prices of their products. This problem can be solved by applying fixed prices for all slaughterhouses as proposed in the JRC PEF.
The advantage of the economic allocation lies in the fact that it is applied by other sectors processing agricultural products. A uniform approach can be helpful in developing a level playing field for all sectors in the agri-food complex.

8.3 Allocation as incentive and benchmark

In the previous sections we discussed the shortcomings of fixed allocation ratios and of unintentionally hiding technical improvements in the economic fractions.

This brings up an aspect of the allocation that hardly has been mentioned in the discussions about allocation, not in the sector organizations, governments or in the academic field. In many of these discussions, too much focus has been on finding the "right" allocation, trying to solve conflicting interests, driven by business interests or political views. The academic world has tried to solve this issue with developing physical relationships between co-products. Especially in biological processes, making agricultural products, it is very hard to disentangle co-products on a physical basis. These approaches still rely on assumptions and methodological choices but will never be able to deal with all methodological problems. Moreover, a technical "perfect" solution will not be able to solve the discussion, as business and policy driven interests and "gut" feeling dominate the discussion.

We need to be aware of the fact that, despite all efforts to develop a perfect allocation and irrespective the chosen allocation, the total of allocation ratios always adds up to 100%. Allocation is not relevant from the point of view of mitigating emissions and to improve environmental performance. Allocation is an approach to try to compare the footprint of various main and by-products, but, given the shortcomings of all allocation approaches, too much weight is given to allocation. It is for good reasons that ISO recommends staying away from allocation. But this is impossible in biological processes as food production and processing.
One of the differences between the plant-based food, dairy processing and the slaughter process is the relatively high fraction of losses while the losses of slaughter process are part of the allocation calculations. Also, here, the total of all allocation fractions adds up to 100%, but it is very essential, to show that improving the slaughter process and reducing the fraction of waste or utilizing waste for energy production is made visible. In this way, allocation can act as an incentive. From that point of view, we have shown in the results that visibility of improving the technical and as a consequence the environmental performance is much clearer shown with the mass fraction than with the economic allocation. However, when the mass fractions are presented per kg of (by)product, equal footprint values are obtained for all (by)products. When the footprint based on economic allocation are reported per kg of (by)product, it results in different footprint values which better reflect the appreciation of the various products, and which is the standard in many economic sectors. Based on the issue explained, we propose an approach which can provide the advantages of both mass and economic allocation methods. In this approach depending on the aim of using allocation, either economic or mass allocation method can be applied. In a case the aim is evaluating the environmental performance of slaughterhouses, it is suggested to apply the mass allocation method. The benefits of using mass fractions have been explained in detail in previous chapters. Therefore, we do not repeat them in this paragraph. In this situation a slaughterhouse with a higher mass fraction for human food products gains higher score in terms of the environmental performance. Using this approach mass fraction plays an important role to incentive slaughterhouses to increase the fraction of human food products. In a case the aim is to identify the share of each economic sector (e.g., pet food, leather, human food, etc.) from the total upstream emissions, it is suggested to apply economic allocation method. Using the economic allocation method, environmental impacts of different (by)products can be presented per kg of (by)product, while using mass allocation leads to equal values for various (by)products. This approach is aligned to the approach suggested by the JRC PEF. It is recommended that all slaughterhouses (or actors in a specific sector) follow the same average prices to minimize the variation and the risk of economic values being the driver of changes in the share of each economic sector from upstream emissions. To have a more realistic prices, it is suggested to use five-year average prices which need to be updated regularly.

The flexible mass fraction values can be also applied in the context of the JRC PEF to show the environmental improvements of slaughterhouses however it is essential to consider the limitation of this approach which has been discussed in detailed in this report.

In line with this finding, it is required to develop clear guidelines for the classification of slaughter products for beef, and pork meat. Slaughterhouses should all apply these guidelines and develop a routine in monitoring technical performance. The national and European meat processing sector organisations should stimulate their members to join this process and to benchmark their results.

9 Conclusions

The aim of this report was to evaluate the variations in mass and economic fractions and to identify the pros and cons of using mass and economic allocation for the upstream emissions to all products (main-, co- and by-products) at slaughterhouse level. Both mass and economic allocation approaches have their own strengths and weaknesses and due to the limitation of each approach and depending on the aim of using allocation, both methods can be applied. In case the goal is benchmarking or incentivizing the slaughterhouses to increase the fraction of human food products, mass fractions can be applied. Whereas if the aim is to allocate upstream emissions to different economic sectors (pet food, leather, etc.), the economic fraction and subsequently the allocation ratio can be applied.

Another conclusion is in relation to the comparison of the suggested values of mass fraction of main-, co- and by-products in the JRC PEF method and the actual situation. Based on the obtained results it was revealed that the mass fractions varied over time and among slaughterhouses, whereas the economic fractions where more stable. Comparisons showed that the JRC PEF method does not reflect the actual situation well. Moreover, the fixed allocation ratios do not reflect the improvements that can be carried out by slaughterhouses. This highlights the importance of the application of primary data to get more accurate and realistic mass fractions. In addition, the JRC PEF method considers no allocation ratios for by-products with zero or negative economic value. However, these by-products might be used for production of other products. To consider these by-products in the allocation process, we suggested to subtract the processing costs from the final value of product (after processing) to determine the economic value of the by-product of Cat. 1 and 2 and the waste streams.

Application of flexible mass fractions and fixed prices in the JRC PEF approach was tested and it was revealed that this approach can reflect the technical improvement of slaughterhouses. However, it is essential to consider that changes in the fraction of other products might have impact on the allocation ratio of edible products.

The data collection for this study was a challenge. We think that systematically recording the required data for such analyses is essential for meat industry for two reasons: i) use this in a precompetitive way for benchmarking to improve their environmental performance; and ii) to enrich discussions with other important players in this field e.g., the European Commission, governments, NGO’s and consumers, for which the availability of transparent data is key. An important recommendation of this research is that more effort is needed for database management within UECBV by developing the required infrastructure and support facility for collecting data, benchmarking and discussions about environmental improvements.

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Wageningen Livestock Research
P.O. Box 338
6700 AH Wageningen
The Netherlands
T +31 (0)317 48 39 53
E info.livestockresearch@wur.nl
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Wageningen Livestock Research is part of Wageningen University & Research. Together we work on the mission: ‘To explore the potential of nature to improve the quality of life’. A staff of 6,500 and 10,000 students from over 100 countries are working worldwide in the domain of healthy food and living environment for governments and the business community-at-large. The strength of Wageningen University & Research lies in its ability to join the forces of specialised research institutes and the university. It also lies in the combined efforts of the various fields of natural and social sciences. This union of expertise leads to scientific breakthroughs that can quickly be put into practice and be incorporated into education. This is the Wageningen Approach.