Livestock meat processing: inventory data and methods for handling co-production for major livestock species and meat products

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ABSTRACT

This study analyzed impacts on global warming, energy demand and consumptive water use from meat processing of four major species, chicken, pork, sheep and beef. We investigated four different approaches for handling co-production between meat and non-meat co-products; allocation based on either i) biophysical / protein utilization (BIO); ii) economic value (ECON); system expansion (SE), and a hybrid approach utilizing both biophysical allocation and system expansion (BIO-SE). The impact from processing varied depending on species and impact category, but for all species, the choice of method used to handle co-products had a substantial impact on results. Impacts attributed to the meat product were lowest when BIO was applied, while the highest impacts were generally associated with ECON. SE results were not uniform across the species or across impact categories. Carcase and human edible yield is also discussed as an important consideration when comparing meat products at intermediate stages in the production supply chain.

Keywords: meat processing, life cycle assessment, meat chicken, pork, sheep meat, beef

1. Introduction

Numerous LCA studies have been conducted for meat production systems in the past 10 years, and many of these (e.g. Williams et al. 2006, Cederberg et al. 2009) have focused on the primary production system to the cradle-to-farm gate section of the supply chain. Meat processing, while being a relatively smaller contributor to impacts than the farming section, is a very important stage in the supply chain from the perspective of handling co-production. Livestock systems generate various important co-products, including leather, pet food, protein meals and tallow. Mass loss during meat processing also results in an increase in emissions attributable to each product irrespective of the method used for handling co-production.

A number of farm-gate livestock LCA studies (Cederberg et al. 2009; Leinonen et al. 2012; Opio et al. 2013; Williams et al. 2006) have reported results using a carcase weight (CW) or even a boneless meat functional unit, creating a mismatch between the functional unit and system boundary. This approach induces two errors; firstly it fails to include impacts associated with the meat processing stage of the supply chain and associated transport, and secondly the method attributes all impacts to the meat product, ignoring the value of the co-products entirely. This is inconsistent with other stages in the livestock system where considerable attention has been given to addressing co-production, such as approaches for handling milk and meat in dairy cattle systems (i.e. Cederberg & Stadig 2003, Flysjo et al. 2012). Processing inventories for LCA purpose have been included for chicken meat (e.g.Bengtsson and Seddon 2013), pork (Nguyen et al. 2011), sheep meat and beef (e.g.Peters et al. 2010; Ridoutt et al. 2012). However, few details were provided in these studies and co-production was often allocated on economic or mass bases. In addition, system expansion of meat processing has not been investigated in detail, and thus the significance of rendering was not fully understood. In a recent study of environmental impacts of rendering, Ramirez et al. (2011) considered animal by-products as wastes and do not include the environmental burden of their production. This ignored the fact that meat processing produces not only meat products for human consumption but also pet food and other valuable products. To the authors' knowledge, the significance of co-product handling has not been thoroughly investigated before.

In this paper, inventory data for meat processing of four species (chicken, pig, cattle, sheep) were collected from meat processing plants in Australia covering greenhouse gas (GHG) emissions, fossil energy demand and consumptive fresh water use. The impact of four methods for handling co-production (biophysical allocation based on utilized protein and energy, economical allocation, system expansion and a hybrid approach utilizing both biophysical allocation and system expansion) were presented at the point of meat processing. The results were compared with allocating all impacts to the meat product only. We suggest here a re-definition of the functional unit for meat products to include the yield of edible co-products that are an important contribution to human food supply.

2. Methods

2.1. Goal and scope

The goal of this study was to provide factors and inventory data representative of modern meat processing facilities in Australia, and to explore the impacts of co-production at the point of meat processing. The focus of the study is meat processing, but to illustrate the relevance of methods for handling co-production, the system boundary includes all stages up to the point where product is ready for transport to wholesale or retail (the meat processing plant loading dock). The functional unit is 1 kilogram of retail portions excluding packaging. The study was based on primary data collected from meat processing plants from a series of studies conducted by the authors (Wiedemann et al. 2010; Wiedemann et al. 2012). These studies also provide details of the cradle to farm-gate stage of the supply chain which have been updated to include direct land use change (dLUC) impacts in the present analysis.

The study determined GHG emissions using the IPCC AR4 global warming potentials (GWP) of 25 for methane and 298 for nitrous oxide (IPCC 2007). Energy demand was assessed using the fossil fuel energy demand indicator (Frischknecht et al. 2007) and measured in mega joules (MJ) using Lower Heating Values (LHV). Consumptive fresh water use refers to evaporative uses or uses that incorporate water into a product that is not subsequently released back into the same river catchment. In the meat processing, consumptive water includes raw water drawn from river/bores/reticulation and used in the processing plant, and subsequently treated via waste water treatment. The water subsequently used for irrigation (without going through sewage system) is not considered consumptive usage. Consumptive water use was assessed following (Bayart et al. 2010). Inventory data are reported for impacts relating to GHG emissions, energy and water while co-product handling methods were compared for GHG and energy demand only.

2.2. Processing inventory data

Inventory data were collected from a minimum of three meat processing plants for each species (Table 1, Table 2). Data from the case study processing plants were validated using a recent survey of resource use from beef and sheep meat processing plants (GHD 2011) for important inputs such as electricity, gas and water to improve the representativeness of the dataset. Inputs were reported per kilogram of Hot Standard Carcase Weight (HSCW) which is a standard descriptor in Australia. However, the inputs are inclusive of all stages of meat processing, which included chilling, boning and rendering of co-products. Importantly it should be noted that the definition of HSCW may vary between species and countries.

2.3. Product Yields

Meat processing yields different products depending on the species. Yields may be determined from primary output data, but in the absence of these data the mass of products may be determined from a series of factors. Here we report the yield of products from processing based on primary data and industry averages applicable in Australia. Yield characteristics vary between different breeds of livestock and this can have a large influence on results. As a consequence, important factors such as the dressing percentage and retail yield should be based on data reflective of the supply chain being investigated. In Table 1 we report data relative to the supply of 1000 kg of retail portions. We consider offal sold for human consumption as part of the functional unit, because this product is functionally equivalent to meat from the animal carcase with respect to nutritional characteristics. The mass of unprocessed rendering material and products from rendering are included.

Table 2 provides critical yield factors to convert live weight of animals to the amount of edible meat after meat processing for each species, including the edible fraction for the retail portions, which differs depending on the amount of bone included in the product sold at retail. This will vary depending on the degree of processing (boning), the degree of trimming for excess fat, and the inclusion or exclusion of skin in the saleable portion for chicken and pork. We specify here the edible portion, meaning the mass of product exclusive of bone and cartilage mass which are not easily digested. Importantly, the mass of meat actually consumed may be lower depending on consumer preferences and this would need to be accounted for during the consumption phase. We include the edible fraction here because it differs considerably between the species and therefore is necessary for correctly interpreting the results.

Table 1. Product mass for four meat species relative to 1000 kilograms of retail product

Product description	Product	Chicken meat	Pork	Sheep meat	Beef
Farm-gate product	Live Weight	1712	1618	2255	2375
Intermediate product	Hot Standard Carcase Weight	1216	1229	1060	1307
Wholesale product	Cold Carcase Weight	1179	1177	1017	1267
Wholesale/retail product	Retail cuts	967	906	895	887
	Edible offal	33	94	105	113
Retail portions (retail cuts + edible offal)		***1000***	***1000***	***1000***	***1000***
	Hides	0	0	169	214
	Pet food	17	84	34	30
Rendering material	Unprocessed meat, bone, offal	593	372	800	989
Rendering Products	Protein meal products	154	53	152	257
	Tallow	73	109	156	154
	Blood meal	5	5	14	14

Table 2. Meat processing yield factors for chicken meat, pork, sheep meat and beef

	Chicken meat	Pork	Sheep meat	Beef
Dressing percent	0.71	0.76	0.47	0.55
Chilling loss	0.03	0.04	0.04	0.03
Retail yield	0.82	0.77	0.88	0.70
Edible offal yield (% of LW)	0.02	0.06	0.05	0.05
Edible fraction of retail portions	0.85	0.85	0.76	0.95

2.4. Co-production

The options for handling co-production according to ISO 14044 (ISO 2006) can be divided into two broad approaches, in order of preference.

Methods to avoid allocation:

- Clear subdivision of the system, or
- System expansion (expanding the product system to include the additional functions related to the co-products to avoid allocation).

Allocation:

- Allocation on the basis of physical or biological relationship.
- Allocation on some other basis; most commonly economic (market) value.

In meat processing, sub-division has been proposed as a method of dividing impacts from meat products and rendering material (Ramirez et al. 2011) though this implies that rendering material is valueless and carries no burden from the production system. This is not valid for important co-products such as hides. Where the system can’t be divided, system expansion and allocation methods are recommended. In practice, a number of studies that have included allocation in meat processing have applied economic methods (i.e. Ledgard et al. 2010; Milà i Canals et al. 2002; Opio et al. 2013).

System expansion is performed by allocating all burdens to the meat product then deducting impacts associated with the production of substitute products. This method relies on the selection of appropriate substitution products, which are typically the marginal primary products in the relevant commodity market. The ease with which substitution products can be identified varies. Animal protein meals are used in most parts of the world (with the exception of Europe) as an important feed ingredient for poultry and pigs. Animal protein meals provide a high value protein feed with a superior amino acid profile and higher levels of phosphorus than vegetable protein sources. None the less, they can and are substituted with vegetable protein sources, synthetic amino acids and alternative phosphorus sources. In the present study, we simplified the substitution process by using soybean meal and cereal grain (in this case sorghum) to create an equivalent level of energy and protein as provided by the animal protein meal. We recognize this is a simplification and could be improved by including additional synthetic amino acids to address specific deficiencies. Soymeal from Brazil and Argentina were considered the appropriate marginal protein source and the impacts from this soymeal were determined following Opio et al. (2013). We acknowledge that in some regions, animal protein meals may be used for alternative purposes such as fertilizer but animal feeding is a more important activity globally. Tallow is used for many purposes; human food, animal feed, cosmetics and biofuel to name a few. Here we substituted tallow for palm oil, which is considered the marginal oil source globally. Pet food was substituted for soymeal on a protein equivalent basis as many manufactured pet foods are heavily reliant on vegetable protein sources. This substitution overlooks one important element; animal meals provide both protein and an important meat flavor for pet food which improves the palatability of these products. Hence, the substitution is incomplete. The last major substitution product was the raw hide, which was only relevant for sheep and beef in the Australian examples. Raw hides are processed into leather and other co-products; typically at a separate facility. Because raw hides are an intermediate product, no direct equivalent exists. To add to the complexity, the final leather product operates as a primary product in premium upholstery, footwear and apparel markets. While substitutions can be found, they may be inferior in terms of market acceptance, value and in some cases durability. We applied a simplified substitution approach by determining the mass of hides that contribute to the final leather product (20%) and substituting vinyl at a ratio of 4:1 by mass (European Commission 2004) to account for the superior wear characteristics of leather (assumed to be 80 years). The greater mass of vinyl was to account for the higher durability of leather for use as upholstery or apparel. The mass of avoided product associated with meat production is provided in Table 1 while the avoided impacts per kilogram of product are provided in Table 3.

Table 3. Avoided products used in System Expansion (EcoInvent)

	GHG	**Energy**
	kg CO_2-e	MJ / kg
Leather substitute	9.7	215.9
Pet food (avoided soy) [a]	1.6	0.6
Animal protein meal (avoided soy) [a]	5.8	2.1
Tallow (avoided palm oil) [a]	1.5	4.3
Blood meal (avoided soy) [a]	9.7	2.0

[a] dLUC has been included for palm oil and soy production.

A biophysical allocation approach was applied by using the mass of utilizable protein and energy in each product (Table 4) based on Kanagaraj et al. (2006) and Meeker (2006). Meat products were assumed to have a standard proportion of protein (0.2) and fat (0.15) and were adjusted for the edible yield of product (Table 1). Hides were adjusted for the proportion of protein utilized in the leather product.

Table 4. Utilisable protein and energy in primary and co-products from meat processing

	Chicken meat	**Pork**	**Sheep meat**	**Beef**
Retail portions	0.30	0.30	0.27	0.33
Hides			0.24	0.24
Pet food	0.09	0.09	0.09	0.09
Secondary Rendering Products				
Animal protein meals	0.60	0.50	0.50	0.50
Tallow	1.00	1.00	1.00	1.00
Blood meal	0.85	0.85	0.85	0.85

The very high levels of utilizable protein and energy in the rendering products was because the rendering process removes excess moisture in comparison to meat, hides and pet food which are all high moisture products. This led to high allocation fractions to these products (Table 5) which were not meaningful considering the minor importance of these products.

Table 5. Allocation fractions based on utilisable protein and energy in primary and co-products from meat processing

	Chicken meat	Pork	Sheep meat	Beef
Retail portions	0.63	0.67	0.48	0.49
Hides	0.00	0.00	0.07	0.07
Pet food	0.003	0.017	0.006	0.004
Secondary Rendering Products				
Animal protein meal	0.20	0.06	0.14	0.19
Tallow	0.16	0.25	0.28	0.23
Blood meal	0.01	0.01	0.02	0.02

Alternatively, we applied a hybridized method where we divided the rendering process from the system and used the utilizable protein and energy to perform a biophysical allocation on the retail portions, hides and pet food (Table 6), combined with a system expansion approach to handle the products from rendering.

Table 6. Allocation fractions based on utilizable protein and energy for retail portions, hides and pet food

	Chicken meat	Pork	Sheep meat	Beef
Retail portions	0.99	0.98	0.86	0.86
Hides	0.00	0.00	0.13	0.13
Pet food	0.01	0.02	0.01	0.01

Economic allocation was based on the value of products leaving the processing or rendering plant. While rendering is a separate process, many plants surveyed could not provide a separate break-down of energy inputs to rendering as distinct from meat processing. Hence we considered the output of meat processing to be inclusive of rendering. The value of hides was for the unprocessed raw product. While this was in line with the system boundary, it resulted in an inconsistency in the economic allocation method because the products were at a different stage of processing. In agricultural systems, product value is often disproportionately distributed to the wholesale and retail end of the supply chain. Hence, bias can be introduced if economic allocation processes are not performed at the same point in the production system for each product. This will result in lower impacts for less processed products (i.e. leather) and higher impacts for more processed products such as meat and animal meals. An interesting alternative not applied here would be to expand the primary processing system to include tanning of leather products to align the production stages for all products. Economic allocation proportions are provided in Table 7. The value of retail portions was based on the wholesale value of all meat products as reported by the meat processing plants and verified using Australian market data where available (APL 2009; MLA 2013a; MLA 2013b).

Table 7. Economic allocation factors for meat products and co-products from four species

Slaughter Products	Chicken meat	Pork	Sheep meat	Beef
Retail portions	97.2%	97.5%	88.3%	89.1%
Hides	0.0%	0.0%	8.0%	5.7%
Pet food	0.2%	0.4%	0.4%	0.5%
Secondary Rendering Products				
Animal protein meal	1.3%	0.5%	1.3%	2.5%
Tallow	1.2%	1.5%	1.7%	2.0%
Blood meal	0.1%	0.1%	0.2%	0.2%
Total	100.0%	100.0%	100.0%	100.0%

3. Results

3.1. Impacts from meat processing

Meat processing varied substantially between species for all impact categories of interest. Energy and GHG emissions were closely associated, though additional emissions also arose from anaerobic waste treatment systems were utilized. Sheep processing was the most energy and GHG intensive, followed by beef processing. These also used the highest amount of water. In the context of the whole supply chain, meat processing was a significant contributor to energy demand for all species.

Table 8. Meat processing impacts associated with processing four different species, expressed as per kilogram of Hot Stand Carcase Weight (HSCW)

	Units	Chicken meat	Pork	Sheep meat	Beef
Global Warming	kg CO_2-e / kg HSCW	0.42	0.40	0.91	0.80
Fossil energy (MJ)	MJ / kg HSCW	4.34	3.00	8.33	5.81
Consumptive Fresh Water Use	L / kg HSCW	2.43	6.57	7.53	8.75

3.2. Handling co-production

Results without allocation are provided in Table 9 using four different reporting units for comparison. The results for HSCW without processing impacts represent a common approach, where impacts are calculated to the farm gate then divided by an assumed dressing percentage without allocation or accounting for processing impacts. Including processing impacts contributed an additional 3-11% with the greatest proportional increase being for chicken meat and the least being for beef. Results are also presented per kilogram of retail meat without allocation.

Table 9. Greenhouse gas emissions (kg CO_2-e / kg product) from four species reported on an unallocated basis per kilogram of live weight, HSCW and carcase retail yield

	Chicken meat	Pork	Sheep meat	Beef
Live weight	2.5	4.4	6.4	11.7
HSCW (no allocation, no processing impacts)	3.5	5.7	13.6	21.3
HSCW (no allocation to co-products, processing impacts included)	3.9	6.1	14.5	22.1
Carcase retail yield (no allocation to co-products, processing impacts included)	5.8	9.8	22.7	34.3

GHG emissions for four species and four methods for handling co-production are shown in Figure 1. Impacts were lowest for the utilized protein and energy method and highest for the economic allocation method, with the system expansion and the hybrid method being intermediate. The utilized protein-energy method was not considered suitable because the allocation to minor rendering products was very high, resulting in higher impacts per kilogram of co-products than the primary product. The difference was primarily because of the difference in moisture content; the retail products have a high proportion of moisture which increases product mass, while the rendering products are dry (90% dry matter). Economic allocation tended to attribute slightly lower impacts to co-products than the comparative system expansion approach, though these were fairly similar across the species. The hybrid method was effective in allocating impacts between the utilized portion of the meat, hides and pet food while avoiding the errors created by including the minor co-products into this method.

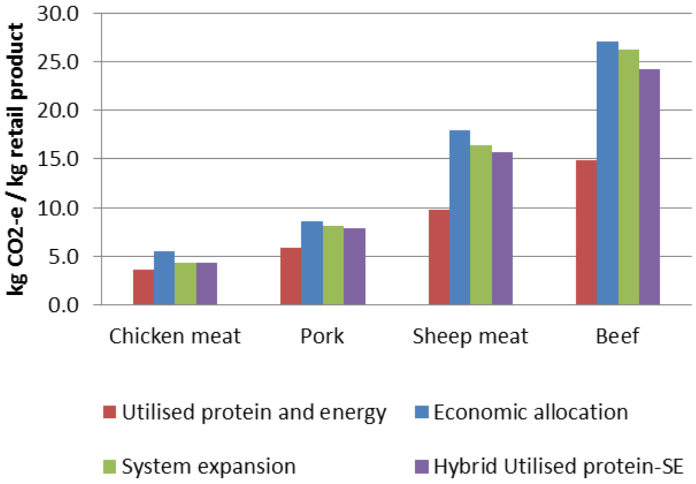

Figure 1. Greenhouse gas emissions for meat products with four alternative methods for handling co-production across four species

The assessment of energy demand (Table 10) followed the same trend as GHG for the allocation method because of the fixed ratios applied to both indicators, but showed strongly divergent results for the SE method for sheep and beef. This was largely influenced by the substitution process for hides, which were replaced by vinyl, which is an energy intensive product.

Table 10. Energy demand from four species reported using four different approaches for handling co-production

	Chicken meat	Pork	Sheep meat	Beef
Economic allocation	21.8	25.0	18.1	20.7
Utilized protein allocation	14.2	17.2	9.9	11.4
System expansion	21.7	24.8	-18.0	-25.5
Hybrid Utilized protein-SE	21.6	24.1	15.7	17.4

4. Discussion

A few Australian studies have found that meat processing contributes a relatively small amount of GHG to the total impacts from meat production, but higher amounts of energy (Peters et al. 2010; Wiedemann et al. 2010; Wiedemann et al. 2012). The contribution is greatest for ‘low impact’ meat species such as poultry where the contribution to GHG was 11% and to energy was 31%. Meat processing is a very important stage in the life cycle of meat products from the perspective of handling co-products. This analysis showed significant differences in the impacts attributed to the meat product depending on whether co-products were taken into account, and depending on which method was used. While it is common in the literature for results to be presented without allocating impacts to co-products, we found this induced a substantial error, over predicting the impacts associated with meat by between 6% and 42% depending on the species and method compared. The use of intermediate reporting units such as carcase weight introduced variation between the species, because of the different final yield relative to carcase weight and because dressing percentages do not take into account the yield of edible offal. For this reason, we preferred a functional unit that represents the retail yield from the animal when the focus is food production. Retail yield is still not uniform, because different species include or exclude different amounts of bone in the retail product and therefore provide a different amount of digestible protein and energy. While accounting for the edible portion of meat is part of the consumption phase of the life cycle, it is useful to report this and take it into account in the interpretation phase, particularly if considering different species. The error induced by reporting results on an unallocated basis related to a number of factors. Firstly, the practice of allocating to carcase weight and retail meat from the carcase, while excluding edible offal products, reduces the apparent product yield. We found no reason to exclude this from the functional unit as it contributes equally to human food supply. Including edible offal in the functional unit reduced the total live weight required for each kilogram of retail product by between 3% (poultry) and 12-13% (sheep and beef).

Of the allocation processes, economic allocation has been most commonly applied to date. Economic allocation resulted in a 6 to 27% reduction in impacts allocated to the meat product depending on species compared to the unallocated process, with the greatest differences coming from ruminants. Across the allocation and system expansion methods, the differences in comparison to the unallocated methods were greatest for ruminant species. This was partly because of the role of edible offal discussed above, and partly because of the handling of the animal hide. In poultry and pigs, animal skin is commonly sold with the retail product, where it becomes part of the consumed product or is thrown away by the consumer. In ruminant species, hides are commonly sent to an additional tanning process to produce leather. Leather is a global benchmark product that functions in the market in a fashion more similar to a primary product than a co-product. It is also a high value product at the wholesale and retail level, though this is not reflected in the raw hide value. Because of the point in the processing supply chain where hides are removed, hides receive a relatively small proportion of the environmental burden compared to the biophysical ‘cost’ of producing hides over the life of the animal. This was evidenced by the higher impacts attributable to hides when applying a biophysical allocation process based on utilized energy and protein in the product. However, we found it difficult to establish a meaningful biophysical allocation process that could cover both the major products (i.e. retail meat and hides) and the minor products from rendering. Similarly, we found it difficult to determine an appropriate system expansion process to handle hides, because they are a raw product rather than a final product. A more thorough analysis is required to assess this by expanding the system to take into account the tanning process also.

We presented here a hybrid method that used the favored biophysical approach to divide impacts between the major products while using system expansion to account for the minor rendering products. While it has been accepted for some time in LCA practice that multiple methods of allocation may be used at different points in the same study, we apply this here for a closely related co-product system coming from the same process. We consider this to be an ideal method for accurately attributing impacts to meat and hides, which are important primary products, while accounting for the lesser volumes of rendering co-products with a more appropriate system expansion method.

5. Conclusion

This paper presents new inventory data, product yields and an exploration of novel methods for handling co-products at the point of meat processing. We suggest here a re-definition of the functional unit for meat products to include the yield of edible co-products that are an important contribution to human food supply. With the re-definition of the functional unit and application of allocation or system expansion methods, impacts attributable to meat products declined by 6-42%. The difference in impacts attributed to the meat product was particularly important for ruminant species, which produced the largest mass of important co-products of all the species. The data and methods presented here provide a starting point for researchers to include this approach for future livestock and meat studies.

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Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6