An original way of handling co-products with a biophysical approach in LCAs of livestock systems

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ABSTRACT

A new biophysical procedure to handle co-products in LCAs of livestock systems, combining subdivision of the system and allocation, has been developed. Systems were divided into animal classes, defined as dedicated to specific physiological functions (e.g. growth) and so to specific products (e.g. animals for meat). When allocation is needed, the environmental burdens of the animal class were attributed to the co-products pro rata the feed energy required to produce them (biophysical causality). This has been applied on cattle, sheep, goat, pig, poultry, rabbit and fish production systems. On the example of some dairy and pig systems, it is shown that the attribution of the burdens to the different co-products of a system changes from one impact category to another. Indeed some resource consumption or emissions are specific to an animal class and then, to a product. A sensitivity analysis, considering five other allocation procedures, allows considering their respective advantages and limits.

Keywords: life cycle assessment, allocation, livestock products, sensitivity analysis

1. Introduction

Life Cycle Assessment (LCA) results depend greatly on methodological choices. One of the most important and much debated choices concerns the allocation of the environmental flows among the co-products. At the moment, the LCA practice is not harmonized regarding the allocation of impacts to the outputs of livestock production systems. However, the question of allocation has been extensively studied, especially concerning milk production.

For dairy systems, in particular since the publication of the IDF standard (IDF 2010), most recent publications use allocation ratios based on feed-energy (Flysjö et al. 2011; Dollé and Gac 2012; Thoma et al. 2013) or feed energy and protein requirements (Cederberg and Mattsson 2000; Basset-Mens et al. 2009; O'Brien et al. 2012) needed to produce milk and animals (live weight). Depending on the authors, this procedure is called biological, physical or biophysical causality allocation. The principle is always to consider the strong causal relationship between physiological requirements, especially for growth and lactation, and the feed use for the production of live-weight and milk. From an author to another, some differences appear in the way it is applied: while IDF (2010) and Thoma et al. (2013) only consider growth and lactation needs and propose a meat/milk ratio, Dollé and Gac (2012) include five requirements, i.e. maintenance, activity, growth, lactation and gestation. Those authors highlighted that choices regarding which physiological requirements are considered could lead to significant differences of allocation ratios for a French dairy system, with 82% of impacts attributed to milk applying the IDF method, to 73% when the five types of requirements are considered. For suckler-beef production systems, it seems that only Nguyen et al. (2012) applied an allocation procedure (comparing allocation on live weight mass, protein mass and economic value through a sensitivity analysis), while other studies did not allocate impacts to the different types of animal produced. Most studies report impacts for an average live-weight, mixing cull cows, young bulls and finishing heifers, even weaners, without considering they provide different qualities of meat and that some of those animals will be slaughtered directly while others will be finished. Looking at the current literature, the situation is the same for other species, such as pork and poultry.

Nevertheless, biophysical allocation seems also relevant for other livestock production systems, especially for beef systems, because it allows having the same approach for dairy and suckler beef systems that both provide beef. When considering the allocation of impacts to the different co-products, the appropriate approach is to refer to the ISO 14044 (2006) hierarchy. First, ISO 14044 suggests that allocation should be avoided as far as the system allows it, by subdivision of the multifunctional process in sub-processes, so that inputs and outputs can be assigned to specific products. When subdivision is not possible, an allocation rule based on physical causality must be preferred to other relationships, such as economic value.

The AGRIBALYSE program has provided a public database of Life Cycle Inventories (LCIs) of French agricultural products at the farm gate (Colomb et al. 2014) according to a common methodology (Koch and Salou, 2014). The reports and summary factsheets of the AGRIBALYSE program are available on line (www.ademe.fr/agribalyse-en), while the full database is available free of charge on demand to ADEME (agribalyse@ademe.fr). Concerning animal production, AGRIBALYSE produced: (1) LCIs for animal systems that provide several co-products (e.g.: milk / cull cow / calf) and (2) LCIs of systems that provide both agricultural products (e.g.: cull sow) and living animals used as inputs in other systems (e.g.: cattle weaners, piglets for fattening units). One of the objectives of the project was to harmonize methodological choices as much as possible between all animal species. In fact, concerning allocation, the aim was to apply the same approach for cattle, sheep, goat, pig, poultry, rabbit and fish production systems.

The purpose of the paper is to present how co-products were handled in the AGRIBALYSE program, outlining amongst others the specific data collection procedure. First, we divided the processes and then we applied a biophysical allocation. Our results were compared to LCA results calculated according to other allocation methods in a sensitivity analysis. The paper focuses on the example of milk / live animals in bovine production but also provides highlights for other systems when relevant.

2. Methods

2.1. The handling of co-products in the AGRIBALYSE program

The biophysical allocation method is based on the causal relationship between feed requirements and the different products of a system: production of milk (or egg, living animal's muscles, wool) and its energy content, are driven by the energy required to support the function of lactation (respectively pregnancy, growth and wool production). Six main functions are identified: maintenance, activity, growth, pregnancy, lactation / egg production, production of wool. These functions are directly related to animal products. In current livestock production systems, most of the time, animal life stages correspond directly to different functions and so, to the corresponding products. Indeed, in all species, females become mature and productive once they have finished the main part of their growth and are then dedicated to the production of milk, calves, piglets, lambs or eggs.

This led us to consider that some life stages of an animal can be attributed to a co-product. Then, life-stages are considered as sub-processes of the whole livestock farming system. In accordance with ISO (2006), allocation can then be avoided by dividing the animal life cycle in several stages that we call "animal classes" corresponding to a characteristic physiological stage (calf to weanling, heifers, milking cows, finishing cows). Inputs and outputs were then assessed for each animal class. The output product of an animal class is a living animal that enters the following animal class, or a sold product (e.g. heifers for replacement in another herd). Figure 1 illustrates this principle for a dairy herd, making the assumption that the growth of the milk cows can be neglected.

Data were collected through a specific tool which allowed splitting information between animal classes (calf, heifers, cows…). Some data were directly available at the animal class level (feed, manure), others were available at the herd or farm scales (energy consumption). These data were attributed to animal classes using technical references (e.g. pro rata for the livestock units). When an animal class yielded a single product, allocation was not needed. When allocation was required (e.g. for the stage "milking cow": milk / calf), this was done pro rata for the estimated metabolic energy required for the various physiological functions of the animal and to produce each co-product. All requirements for the different functions were considered and not only those directly linked to a function yielding a product. Then, for the milking cows, part of the maintenance and activity functions was allocated to milk, while the other part was allocated to the calf.

The procedure developed to handle co-products in livestock systems is then a combination of division of the system and allocation.

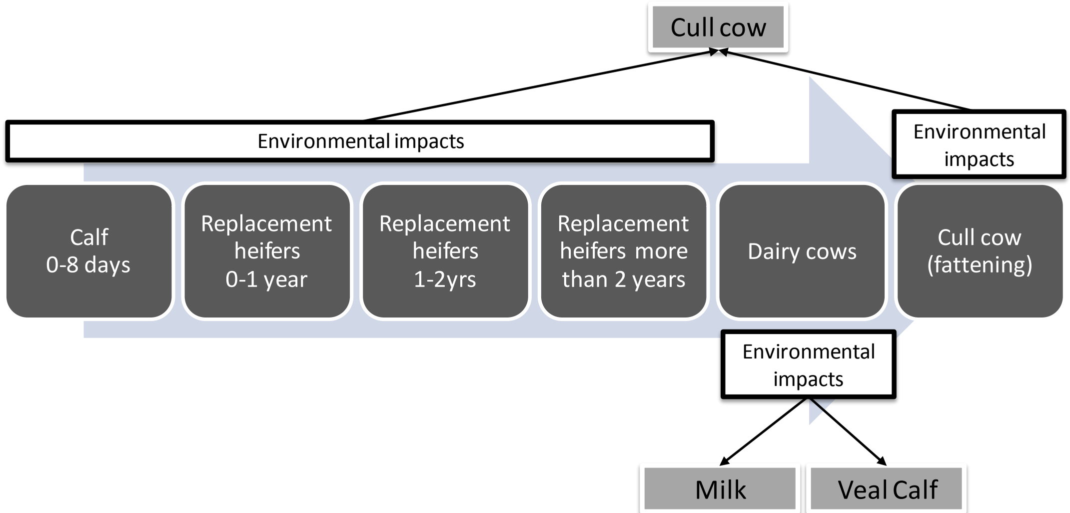

Figure 1. Allocation of inputs and impacts to co-products using a “bio-physical” representation of a dairy herd (blue: animal classes allocated to the cull cow; green: animal class allocated to milk and calves).

Table 1 provides an extract of how animal classes and their estimated requirements for the different functions were attributed to the different co-products. The energy requirements were calculated using equations from NRC (1996, 2001) for cattle in accordance with IPCC (2006) for enteric methane assessment, and national models for pork and poultry (Sauvant et al. 2004). All details are available in Koch and Salou (2014).

Table 1. Animal classes, output products and physiological functions, for allocating environmental impacts depending on the energy required for these functions.

Systems	Animal class	Output products	Physiological functions						Comments / Formulae
			Maintenance	Activity	Growth	Lactation / Egg	Gestation	Wool	
Dairy systems	Calf 0-8 days	Veal calf	X	X	X				
	Rplt Heifer 0-1yr	Cull cow	X	X	X				
	Rplt Heifer 1-2 yr	Cull cow	X	X	X				
	Rplt Heifer +2 yr	Cull cow	X	X	X				
	Milking cow	Milk	X	X		X			$Lactation + (Maintenance + Activity) * \left(1 - \frac{Gestation}{Lactation}\right)$
		Veal calf at birth	X	X			X		$Gestation + (Maintenance + Activity) * \left(\frac{Gestation}{Lactation}\right)$
	Finishing cow	Cull cow	X	X	X				
Beef systems	Calf 0-weanling	Weaner	X	X	X				
	Rplt Heifer 0-1yr	Cull cow	X	X	X				
	Rplt Heifer 1-2 yr	Cull cow	X	X	X				
	Rplt Heifer +2 yr	Cull cow	X	X	X				
	Suckler cow	Weaner	X	X		X	X		
	Finishing cow	Cull cow	X	X	X				
Pigs	Sows and piglets	Cull sows	X	X	X				
		Pig for pork				X	X		
	Post weaning	Pig for pork	X	X	X				
	Fattening	Pig for pork	X	X	X				
Layers	Chick –repro	Cull hen	X	X	X				
	Hen – repro	Cull hen	X	X			X		
	Chicken	Cull hen	X	X	X				
	Layers	Egg	X	X		X			

2.2. Sensitivity analysis

A sensitivity analysis comparing the proposed biophysical method with other methods for co-products handling was carried out on one of the five dairy systems assessed in the program (lowland, maize + grass) to analyze the consequences in terms of allocation factors and climate change impact values obtained. Six allocation methods were tested.

System expansion is the first step suggested by ISO (2006). It was performed considering that the meat from dairy cull cows and from dairy calves replace the average meat produced by the suckler and finishing beef systems analyzed in the AGRIBALYSE program (a mix of suckler cows, heifer and young bulls: 16.23 kg CO_2 eq./kg LW).

Economic allocation was done using data from the case study which provided the price of milk and animals sold for the year 2008 (Réseaux d'Elevage, 2009).

For the protein allocation, protein production by milk and animals were derived from the production of the farm and the average amount of protein in milk (33.2 g/liter) and the amount of protein per kg of live weight (150 g/kg) (CORPEN 1999).

The IDF allocation factor was calculated following the equation provided (IDF 2010):

$$R = 1 - 5.7717 * (\text{meat} / \text{milk}) \quad \text{Eq. 1}$$

The biophysical allocation method proposed by Dollé and Gac (2012) for dairy herds helps to consider the five functions in a simple way: all the functions of milking cows are allocated to milk, except pregnancy dedicated to the sold veal calves and all the functions of replacement heifers are allocated to the cull cow (including pregnancy, considering it contributes to the replacement calves).

Another allocation rule is added, derived from the AGRIBALYSE procedure, where energy requirements are attributed to the co-products in the same way (Table 1) to establish allocation factors (cull cows: all requirements of the replacement heifers; veal calves: requirements for pregnancy of the cows and a part of their maintenance and activity, plus the requirements of the dairy calf until they're sold; milk: requirements for lactation of the cows and a part of their maintenance and activity).

3. Results

3.1. Consequences of the AGRIBALYSE procedure on allocation factors

A selection of results in Table 2 presents how the impacts are distributed to each co-products for the five dairy systems studied in the AGRIBALYSE program. The resulting factors vary from one system to another, depending on its technical performances (milk production per cow, replacement rate, etc.). They also change from one impact category to another, because some impacts are specifically linked to one stage of production. For instance, considering milk production, the highest factor is always the one for non renewable energy, because of the energy consumption of the milking parlor.

Table 2. Distribution of the impacts with the AGRIBALYSE biophysical procedure for two impact categories and five dairy systems.

Impact category		**IPCC GWP 100a**			**Non renewable Energy fossil + nuclear**		
Co-products		Calf	Cull cow	Milk	Calf	Cull cow	Milk
Functional unit		1 kg LW	1 kg LW	1 kg FPCM	1 kg LW	1 kg LW	1 kg FPCM
Dairy systems	Lowland - Maize	1.5%	17.8%	80.7%	1.6%	12.9%	85.5%
	Lowland - Maize + Grass	1.5%	22.9%	75.6%	1.7%	15.7%	82.6%
	Lowland - Grass	1.9%	29.2%	68.9%	3.1%	17.1%	79.8%
	Lowland - Grass - Organic	2.0%	23.6%	74.4%	2.3%	15.0%	82.7%
	Highland	2.6%	19.7%	77.7%	3.0%	8.8%	88.2%

LW: Live Weight; FPCM: Fat and Protein Corrected Milk.

Amongst the co-products of a whole pig production system (breeding and fattening), the impacts are mainly supported by the fattened pigs, while cull sows carry less burdens. It is due to the fact that nearly 20 pigs are produced per sow per year. The fattening pigs are the product that the farms intend to produce and the sows are a tool of production even if their meat is valorized. Two contrasting types of production (conventional and organic) (Table 3) show the high allocation factors for fattening pigs for the impact climate change (86% and 92%). The allocation factor for fattening pigs is higher for organic production because the housing mode of the pigs is on litter. More GHG are emitted than on the slatted floor of the conventional production. Despites this high allocation factor for fattening pigs, the impact values per kg live animal are higher for culled sows than for fattening pigs (11.54 kg CO_2 eq. / kg of culled sow *vs* 2.4 kg CO_2 eq. / kg of fattening pig). This is due to the live weight production of each animal class. This allocation factor doesn't reflect the economic value of the products, respectively 93.5% of the income coming from pig sales and 6.6% from sows.

Table 3. Biophysical allocation factors obtained for two impact categories and two pig systems.

Impact category		**IPCC GWP 100a**		**Non renewable Energy fossil + nuclear**	
Co-products		Pig for pork	Culled sow	Pig for pork	Culled sow
Functional unit		1 kg LW	1 kg LW	1 kg LW	1 kg LW
Pig production	Organic	91.8%	8.2%	84.4%	15.6%
	Conventional	85.6%	14.4%	85.3%	14.7%

3.2. Sensitivity analysis results

The sensitivity analysis performed shows that the carbon footprint (CF) of the milk in the maize + grass system varied from 0.70 to 1.14 kg CO_2 eq./ kg FPCM (Table 4) depending on the co-product handling. These results are in the range of values from the literature. The CF varies from -27% to +17% comparing with the value provided by AGRIBALYSE. It has much more consequences on the impact of the carbon footprint of live weight animals, dedicated to produce meat directly (cull cows) or to be finished (calf): from -54% to +110%.

Table 4. Effect of the co-product handling procedure on allocation factors (in %) and carbon footprints (CF) of milk, cull cow and veal calf for a French lowland dairy system based on silage maize and grass dairy system (in kg CO_2 eq. per kg of FPCM and per kg of LW)

	Veal calf		Cull cow		Milk	
	factor	CF	factor	CF	factor	CF
Economic allocation	1.2%	6.10	10.4%	4.01	88.4%	1.14
Protein allocation	1.0%	5.01	13.0%	5.01	86.0%	1.11
Biophysical allocation (IDF)	1.5%	7.45	19.4%	7.45	79.1%	1.02
Biophysical allocation (Dollé & Gac, 2012)	2.9%	14.71	19.3%	7.40	77.8%	1.00
Biophysical allocation – derived from AGRIBALYSE	5.3%	27.02	19.3%	7.40	75.4%	0.97
Division + allocation - ABRIBALYSE® -	1.5%	7.73	22.9%	8.80	75.6%	0.98
System expansion	-	16.23	-	16.23	-	0.70

4. Discussion

Advantages and limits of each allocation procedure tested are discussed here. In our example, economic allocation provides the highest carbon footprint of the milk. It allows attributing impacts to each co-product, related to its market value. It shows the real interest for each of the co-products. However, the economic value of a dairy calf at the dairy farm gate does not represent the final use of this co-product which continues its life cycle in a finishing unit. To exclude the effects of short-term price variability, economic allocation should be done using average prices based on data for several years, however, this has not been possible here. Another point concerning economic allocation is that it could be not relevant when comparing productions from different countries, with different races. The example of sheep production in France and New Zealand is relevant: in France, wool provides little economic profit, while in NZ, because of the more productive races and an existing market for carpet making, the wool has a good value (Gac et al. 2012).

Protein allocation is oriented by the protein content of each co-product leaving the farm, in relation to their destination as human food. It doesn't help distinguishing cull cows and calves as they have both the same functional unit (kg of live weight). The results of carbon footprints are close to those obtained with the economic approach.

The IDF (2010) method provides also the same results for cull cows and calves. That is explained by the fact that this physical allocation method is based on a milk/meat ratio which treats all animals dedicated to meat production in the same way. This is probably linked to the fact that this allocation method was developed specifically for the dairy sector and didn't aim at specifying each co-product.

The biophysical allocation methods of Dollé and Gac (2012) and the one derived from AGRIBALYSE assign less energy requirements to milk. This results in a lower carbon footprint for milk and a higher carbon footprint for live animals, in particular for the veal calf. When those allocation procedures are applied, the carbon footprint of dairy animals at the farm gate is much closer to that of animals from suckler beef systems. This point is relevant because these two types of beef are sold in the same market. Beef from dairy cows is important, as it represents 23.5% of the French beef production (Institut de l'Elevage, 2013). This method helps also to properly consider French mixed races (Normande, Montbelliarde) which produce less milk and more meat than specialized milk breeds such as Holstein Frisian.

System expansion yielded the lowest carbon footprint of milk. It considered that beef from dairy herds is comparable to other types of beef. This is based on the fact that beef from culled dairy cows is sold in the same markets and for the same uses (mainly human food), despite their difference in terms of quality and price. However, in the way we applied system expansion, it was not possible to distinguish the kilograms of live weight of cull cows and of calves: the former is dedicated to being slaughtered, while the latter will be finished in specific farming units. System expansion should have included finishing of dairy calves and the comparison with suckler calves to be consistent regarding all three co-products (milk, dairy calves, cull cows). Anyway, this way of handling co-products provides impact values for the main product (milk), but does not provide impact values for the other co-products. System expansion could be applied on a dairy system to determine the impacts of calves and cull cows by substituting cow milk by milk of other species (goat, sheep). However, this is quite an unrealistic hypothesis, since goat and sheep milk really serve different markets and needs than cow milk (mainly cheese processes). This example illustrates a weak point of the system expansion approach, as finding an equivalent product is often difficult. Furthermore the system expansion approach is quite subjective because the result is closely dependant on the scenario of substitution that was chosen.

Finally, the procedure applied in the AGRIBALYSE program provides intermediate results, both for milk and for living animals. The corresponding allocation factors are very close from those of Dollé and Gac (2012) for carbon footprint, due to similar methodology: the main difference is the attribution of the maintenance and activity energy needed by cows which are there distributed between milk and calf. However, the allocation factors can deviate when considering other impacts (Table 2). Indeed, the specificity of this approach is that it provides allocation factors specifically for each impact category. This makes sense because, even if feed intake is the main driver of animal excretion and most of the emissions and impacts (climate change, acidification, water use), but this is not the case for all impact categories, specifically for energy demand and land occupation, and eutrophication to a less extent.

5. Conclusion

This paper proposes a new way to handle animal co-products at farm gate, based on a bio-physical approach, coupling subdivision of the system and allocation for the first time. This method is relevant for all livestock systems; it is applicable either for milk, meat, egg or wool. It is also relevant for all impact categories, whenever if they are led or not by animals consumptions and excretions. System subdivision allows determining environmental impacts at for each animal development stage, which can be useful to consider impacts of every type of living animal at the farm gate, even if they don't have the same destination: slaughtering, finishing or replacement. In this way, inputs and emissions are directly attributed to the corresponding stage and product. From the farmer's perspective, this approach would help to reconsider the multifunctionality of the production even on specialized systems. Mitigation options or practices improvements would then either be chosen to be adopted on the whole farm or to firstly lower the environmental footprint of the main product.

However, this method requires an appropriate data collection tool and detailed primary data per animal class, which can be quite difficult to obtain. If this is not possible, the alternative is the application of biophysical allocation factors, such as the one proposed derived from the AGRIBALYSE procedure, uniformly on the different impact categories. This first application at a large scale, should know probably be improved by using national models for feed requirements and the way in which the physiological functions are attributed to the different co-products is open for discussion and for further improvement.

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This paper is from:

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

LCA Food 2014

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