Life Cycle Assessment of French livestock products: Results of the AGRIBALYSE® program

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ABSTRACT

In 2009 two French laws were passed on the provision of reliable and complete environmental information on “product plus packaging” to consumers. The AGRIBALYSE programme has produced an LCI database of agricultural products at farm gate to: i) support environmental labelling and ii) provide benchmarks for improving agricultural production systems. AGRIBALYSE analysed a wide range of animal Product Groups and Contrasted Production Systems. LCIs were calculated using a single methodological frame (Koch and Salou, 2014). The Functional Unit for the study was kg (life weight, Fat and Protein Corrected Milk, egg). The indicators Global Warming Potential, non-renewable fossil energy demand, acidification, eutrophication and land occupation were analysed. This paper presents a synthesis of AGRIBALYSE results with a focus on pig production systems. In the last part of this paper we expressed our results using an economic allocation method to better compare them to literature references.

Keywords: Livestock production, Life Cycle Assessment, LCI database, Review

1. Introduction

In 2009 two French laws were passed on the provision of reliable and complete environmental information on “product plus packaging” to consumers. The Life Cycle Assessment (LCA) method was chosen to assess environmental impacts of goods. ADEME, the French Environment and Energy Management Agency, was mandated to set up a Life Cycle Inventory (LCI) database to support this policy. The AGRIBALYSE program (Colomb et al., 2014) started in 2010, involving: i) ADEME as project coordinator; ii) Agroscope (Switzerland) for plant production and INRA for animal production as project co-leaders; iii) CIRAD, ACTA and 10 technical agricultural institutes as project partners. The aim of AGRIBALYSE was to provide LCIs of French agricultural products at farm gate to: i) support environmental labelling and ii) provide benchmarks for improving agricultural production systems. To ensure consistency between the various products of the database, a general methodological framework for the programme was defined (Koch and Salou, 2014). It was decided that the methodologies used and the deliverables must be consistent with ILCD recommendations (JRC and EIS, 2010). The database contains LCIs for 28 crop and 18 animal products, for many products several LCIs exist, reflecting different production systems. In total 113 LCIs are available in a unit process format (www.ademe.fr/agribalyse-en).

In this paper, we first present the AGRIBALYSE database results for animal products. The second part of the article focuses on the environmental impacts of pig production systems. The third part compares AGRIBALYSE results to literature results for animal product LCAs.

2. Methods

2.1. Choice of systems studied

Within AGRIBALYSE, the choice of systems studied was based on an analysis of agricultural products most consumed in France (BIO IS, 2010). Studied systems were chosen according to two main criteria: i) systems representative of French production, to match the first objective of AGRIBALYSE; ii) contrasted or innovative systems, to match the second objective. For animal production, 44 systems, distributed within18 product categories, have been studied (Koch and Salou, 2014).

2.2. Methodology for LCA

The Functional Units (FUs) retained were kg of live weight, kg of Fat and Protein Corrected Milk (FPCM) and kg of egg. Inventories were calculated from "cradle to farm gate", so transformation processes were not included. Emissions and resource use for animal productions were calculated according to Koch and Salou (2014). The models used to calculate direct emissions from livestock production are presented in Table 1.

Livestock production systems are often multifunctional and thus a production system frequently produces two or more co-products. Consequently, a method to assign environmental impacts to co-products is needed. ISO 14044 (2006) gives recommendations concerning co-product handling: i) avoid allocation; when allocation is unavoidable, allocate the impacts according to ii) a physical criterion that reflects the underlying relationships between the co-products, or iii) the economic value of each co-product. To match these recommendations, AGRIBALYSE developed a two step "biophysical" approach to handle livestock co-products (Koch and Salou, 2014). In the first step, allocation is avoided by dividing the production system in several unit processes. Each of these corresponds to a characteristic physiological stage of the animal. When a stage yields a single product, all impacts are attributed to this product. Thus for several stages, allocation is avoided. For stages yielding several products, allocation is based on the metabolic energy required to produce each co-product. The metabolic functions considered are: maintenance, activity, growth, lactation, gestation and wool production.

Table 1. Models used in the AGRIBALYSE program to calculate emissions and resource use directly linked to livestock production. CO_2: carbon dioxide; VOC: volatile organic compound; SO_X: sulphur oxide; NO_X: mono-nitrogen oxides.

Substance emitted / Resource consumed	Source of emissions / consumer of resource	Literature reference for model used
Ammonia (NH_3)	Animal excretion (building/storage)	
	- calculation of nitrogen excreted	CORPEN 1999a, 1999b, 2001, 2003 and 2006
	- emission factors	EMEP/EEA 2009 Tier 2
Combustion gas	CO_2	ecoinvent v2 (Nemecek and Kägi 2007), using an LCI "combustion of diesel/kerosene" data set
	Other air pollutants (metals, VOC, SO_X, NO_X…)	
Methane (CH_4)	Animal excretion (building/storage/grassland/outdoor run)	IPCC 2006 Tier 2
	Emissions from enteric fermentation: cattle and sheep	IPCC 2006 Tier 2
	Emissions from enteric fermentation: other animals	IPCC 2006 Tier 1
Nitrate (NO_3)	Outdoor runs	Basset-Mens et al (2007)
Nitric oxide (NO)	Buildings and storage	EMEP/EEA 2009 Tier 1
Dinitrogen oxide (N_2O)	Buildings and storage	IPCC 2006 Tier 2
Land transformation	All types of production	ecoinvent v2 (Frischknecht et al. 2007)
Phosphorus , nitrogen, total suspended solids (TSS)	Aquaculture	Papatryphon et al. (2005)

Several impact indicators have been retained for AGRIBALYSE (Koch and Salou, 2014), following ILCD recommendations. Indicators such as: GWP_{100} (IPCC 2006); acidification CML 2001 (Guinée et al. 2002); eutrophication CML baseline 2000 2.5 (Guinée et al. 2001); land occupation CML 2001 (Guinée et al. 2002); non renewable energy, fossil + nuclear SALCA (pers. com. SALCA – Swiss Agricultural Life Cycle Assessment) have been studied.

2.3. Comparison with other studies

The selection of the LCA studies for the comparison (Table 5) was based on a modified version of the criteria defined by de Vries and de Boer (2010). Our criteria were: i) studies published in peer-reviewed scientific journals or scientific reports; ii) studies from OCDE countries and partners; iii) studies of systems that produce pig, poultry, beef, milk, egg or fish; iv) attributional LCA studies; v) studies using economic allocation for co-products; vi) "cradle to farm gate" studies; vii) studies published after 2004.

A common FU is needed to compare our results to literature results. When necessary, literature results were recalculated to match AGRIBALYSE FUs. In this article, we focussed the comparison on GWP. To facilitate comparison, AGRIBALYSE results were recalculated using economic allocation instead of biophysical allocation. Economic allocation factors used and sources for economic data are presented in Table 2.

Table 2. Economic allocation factors and sources used to recalculate AGRIBALYSE results.

Products	Sources and allocation factors (%)	Products	Sources and allocation factors (%)
Cow milk	Nguyen et al. (2013)	*Goat milk*	Kanyarushoki et al. (2009)
Milk	86.6	Milk	97
Calf	4.2	Cull goat and kid goat	3
Cull cow	9.2		
Suckler cow	Nguyen et al. (2012)	*Pig*	Basset-Mens and van der Werf (2005)
Cattle weaner	68	Pig	93.5
Cull cow	32	Cull sow	6.5
Ewe milk	IDELE (2011), A. Gac (IDELE) pers. com. (2014)	*Egg*	P. Ponchant (ITAVI) pers. com. (2014)
Milk	79.9	Egg	99
Cull ewe	2.8	Cull hen	1
Lamb	17		
Wool	0.3		

3. Results and discussion

A synthesis of AGRIBALYSE animal product LCA results is presented in Table 3[1] (detailed results available: www.ademe.fr/agribalyse-en). Relative to current LCI databases and LCA results for agricultural products the AGRIBALYSE database presents a major advance, as it contains detailed LCI data for a wide range of agricultural products at farm gate, using a homogeneous methodology. For several products a large number of variants, corresponding to different production systems (13 systems for beef, 6 systems for cow milk; 8 for pigs, 6 for eggs, 9 for poultry), are available. Furthermore, AGRIBALYSE contains some products (goat and sheep milk, rabbit, duck, turkey) for which very little or no LCA results were available so far.

Due to the limited size of this paper we will focus our analysis on results for pig production. Several scenarios for feed supply and overall production system were compared to the reference scenario, which represent an average conventional production of pig in France (Table 4). The impacts of the three "feed" scenarios are quite similar to those of the reference scenario. An increase of land occupation is observed for *Pig, fed rapeseed meal*, because rapeseed meal had a higher land occupation than the raw materials it replaced. A modest increase of all impact categories is observed for the *Pig, fed soybean meal* scenario. The *Pig, on-farm feed supply* scenario requires less energy that the reference scenario, as feed is mainly produced on-farm less transport is required.

Table 3.Summary of AGRIBALYSE LCA results[1] for animal products, using a biophysical approach for co-product handling. Means represent an average of impact values of all inventories calculated for a product category within AGRIBALYSE. Results are expressed per kg FPCM (Fat and Protein Corrected Milk) for milk, kg of live weight for animals, kg of egg. CV: Coefficient of Variation.

			Product category								
			Cattle for beef	**Cow Milk**	**Ewe Milk**	**Goat Milk**	**Pig**	**Egg**	**Poultry**	**Rabbit**	**Fish**
Number of systems studied			13	6	1	1	8	6	9	1	3
GWP	**Mean**	**kg CO2 eq**	11.4	0.9	1.5	0.8	2.5	1.8	2.8	2.3	2.9
	Median	**kg CO2 eq**	11.3	0.8	-	-	2.4	1.7	2.9	-	2.4
	CV	**%**	36.5	14.7	-	-	16.2	17.9	24.4	-	45.1
Acidification	**Mean**	**g SO2 eq**	135.3	8.9	25.1	17.5	40.2	38.8	45.5	14.3	14.1
	Median	**g SO2 eq**	136.7	8.6	-	-	35.8	38	44.7	-	12.4
	CV	**%**	33.5	17.5	-	-	18.7	12.2	26.8	-	31.7
Eutrophication	**Mean**	**g PO4 eq**	45.8	3.8	8.9	5.4	16.9	15.3	19.3	7.1	101.8
	Median	**g PO4 eq**	43.0	3.6	-	-	14.1	15.1	18.9	-	56.7
	CV	**%**	29.7	12.2	-	-	77.5	33.7	45.1	-	80.6
Land occupation	**Mean**	**m2a**	21.3	1.6	4.7	1.6	4.7	3.6	4.8	2.8	1.5
	Median	**m2a**	16.6	1.4	-	-	3.7	3.2	4.3	-	1.6
	CV	**%**	58.6	29.5	-	-	51.6	33.7	37.2	-	16.8
Energy Non renewable fossil + nuclear	**Mean**	**MJ eq**	27.5	2.9	4.9	8.5	16.4	16.8	24.9	23.1	49.6
	Median	**MJ eq**	26.5	2.9	-	-	16.5	16.3	24.3	-	41.2
	CV	**%**	53.5	8.5	-	-	4.2	10.1	24.4	-	32.3

Table 4. AGRIBALYSE LCA results of for pig production systems, calculated using the AGRIBALYSE "bio-physical" allocation method.

System	**Scenario**	**GWP**	**Acidification**	**Eutrophication**	**Land occupation**	**Energy**
		kg CO_2 eq	**g SO_2 eq**	**g PO_4^{3-} eq**	**m^2a**	**MJ eq**
Pig, French average, conventional production	Reference	2.40	35.2	13.6	3.41	17.0
Pig, fed rapeseed meal, conventional	Feed	2.36	35.5	14.0	3.78	16.6
Pig, fed soybean meal, conventional	Feed	2.51	35.8	14.1	3.60	17.6
Pig, on-farm feed supply, conventional	Feed	2.33	35.0	13.9	3.49	15.6
Pig, excess slurry treatment, conventional	Production System	2.42	35.9	14.0	3.90	16.6
Pig, pig with outdoor run, Label Rouge quality label	Production System	2.83	40.9	15.3	3.66	16.4
Pig, pasture system, Label Rouge quality label	Production System	2.15	49.5	19.8	5.48	15.4
Pig, organic production	Production System	3.47	54.4	30.5	10.56	16.7

For the comparison of production systems, our results show an increase of land occupation for the scenario *Pig, excess slurry treatment*. The use of feed raw materials with higher land occupation than in the reference scenario, explain this difference. The two *Label Rouge* scenarios and the *Organic* scenario used less energy (respectively 4%, 9%, 2%), because the animals live outdoors or in buildings that are not heated nor mechanically ventilated. The systems *Pig, with outdoor run, Label Rouge* and *Pig, organic* used deep litter in buildings, which favours N_2O emission. Consequently, they presented higher GWP impacts. Acidification, eutrophication and land occupation impacts were higher than the reference for the *Pig, pasture system Label rouge* scenario and for the *Pig, organic* scenario. This results from the presence of pigs on pasture in these systems. For *Pig, organic*, which presented the highest values, this trend was reinforced by the use of organic crops as the raw materials for the animal feed. Organic crops had lower yields than conventional crops and consequently higher land use per kg product, while emission per hectare were similar. For those systems, the technical performances (kg feed per kg animal growth) were also lower, which led to an increase of many impacts.

Once converted using economic allocation, AGRIBALYSE results for GWP were compared to results from the literature (Table 5, Figure 1). For most livestock species AGRIBALYSE results were in the same range of values as literature results, except for pigs and eggs where AGRIBALYSE results presented less variability and were in the lower range of literature values. The variability observed has three major causes.

Table 5. Summary of AGRIBALYSE results[1] and selected studies from the literature for GWP. Results were calculated using economic allocation. Means represent an average of GWP value of all inventories calculated for a product category within AGRIBALYSE or literature. Results are expressed per kg FPCM (Fat and Protein Corrected Milk) for milk, kg of live weight for animals, kg of egg. CV: Coefficient of Variation.
1: Williams et al. (2006); 2: Katajajuuri (2008); 3: Casey and Holden (2006); 4: Basset-Mens et al. (2009); 5: Casey and Holden (2005); 6: Thomassen et al. (2008); 7: Thomassen et al. (2009); 8: Kanyarushoki et al. (2009); 9: Basset-Mens and van der Werf (2005); 10: Mollenhorst et al. (2006); 11: Seguin et al. (2013); 12: Leinonen et al. (2012); 13: Prudencio da Silva (2014); 14: Boissy et al. (2011); 15: Aubin and van der Werf (2009).

Product category	**Number of systems studied**	**GWP**			**Product category**	**Number of systems studied**	**GWP**		
		Mean	**Median**	**CV**			**Mean**	**Median**	**CV**
		kg CO_2 eq		**%**			**kg CO_2 eq**		**%**
Cattle for beef					*Egg*				
AGRIBALYSE	13	9.44	9.84	62.9	AGRIBALYSE	6	2.49	2.50	15.6
Literature[1,3]	7	8.70	8.62	35.9	Literature[1,10,11]	9	3.88	4.30	30.3
Cow Milk					*Poultry*				
AGRIBALYSE	6	1.05	0.97	17.2	AGRIBALYSE	9	2.88	2.96	24.5
Literature[1,4,5,6,7,8]	10	1.28	1.36	12.4	Literature[1,2,11,12,13]	10	2.59	2.30	30.4
Goat Milk					*Fish*				
AGRIBALYSE	1	1.03	1.03	-	AGRIBALYSE	3	2.96	2.41	45.1
Literature[8]	1	1.32	1.32	-	Literature[14,15]	4	2.71	2.51	24.1
Pig									
AGRIBALYSE	8	2.74	2.62	14.5					
Literature[1,9]	6	4.10	4.65	24.6					

The first source of variability is the diversity of production systems. Indeed, both for the literature results and within AGRIBALYSE, many different production systems exist within a product category. This is particularly true for “cattle for beef” where different production systems, but also different types of animals (dairy cull cow, dairy calves, suckler cull cow, suckler cow) are represented.

The second source of variability is the LCIA method used. The GWP results presented here have been calculated according different methods: Houghton et al. (1994) for the study by Thomassen et al. (2008); IPCC 1996 for the studies by Casey and Holden (2005, 2006); IPCC 2001 for the studies by Williams et al. (2006), Katajajuuri (2008), and Thomassen et al. (2009); IPCC 2006 for AGRIBALYSE, Leinonen et al. (2012), Nguyen et al. (2012, 2013) and Prudencio da Silva et al. (2014). This heterogeneity contributes to the variability of the results.

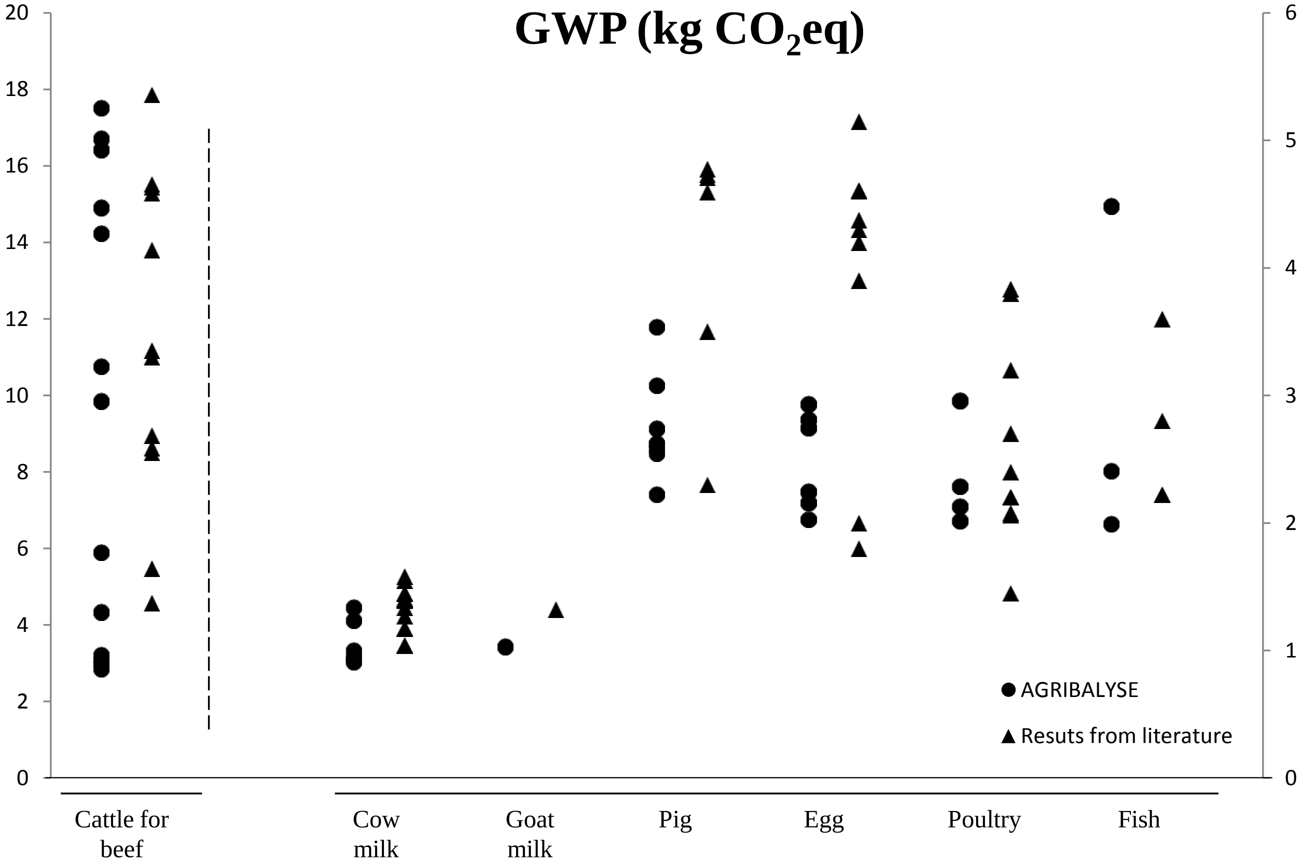

Figure 1. GWP values for products at the farm gate. AGRIBALYSE results[1] are compared to literature references. All results were calculated using economic allocation. Results are expressed per kg FPCM (Fat and Protein Corrected Milk) for milk, kg of live weight for animals, kg of egg. For "Cattle for beef" see left scale, for other products see right scale.

LCI methodological choices are the third source of variability. While all the studies are "cradle to farm gate", many aspects of system modeling vary from one study to another. This particularly concerns the models used to calculate direct emissions, which vary greatly between the selected studies. As an example, N_2O emissions have been calculated according several methodologies depending on studies. Gac et al. (2006, 2010), IPCC (1996, 2000, 2006), UNECE (1999), van der Werf et al. (2009), MfE (2006), among others, have thus been used.

4. Conclusion

AGRIBALYSE provides a large LCI database containing data for French crop and animal products. Its objective is to provide references for a wide range of production systems to support environmental labelling of products and redesign of production systems for improved eco-efficiency. As shown for pig production, the great diversity of production systems of the database combined with AGRIBALYSE methodological framework allows an accurate analysis of farming systems and a transparent comparison of their environmental impacts.

Our results also show that the AGRIBALYSE methodological framework produces results that are largely consistent with literature references, even if differences due to the three sources of variability identified in this article remain.

[1] The results presented here anticipate several corrections that will be taken into account within the version V1.2 of the database. This version V1.2 will be published at the beginning of 2015.

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