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Environmental impacts of milk production in southern Belgium: estimation for nine commercial farms and investigation of mitigation via better manure application

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ABSTRACT

Cattle milk production is strongly criticized for its impacts on the environment. For the first time an LCA approach was used to estimate them in southern Belgium. Based on a 9-farms survey, mean (SD) environmental impacts of 1 kg of fat-and-protein-corrected milk were estimated as 8.4 (4.5) g PO₄eq, 15.5 (2.8) g SO₂eq, 1.4 (0.2) kg CO₂eq, 3.0 (2.9) CTUe, 3.8 (1.2) MJ and 4.6 (0.7) m².yr for eutrophication, acidification, climate change, ecotoxicity, cumulative energy demand, and land occupation, respectively. Improved practices for manure application to land according to UNECE (2007) were simulated for 7 farms as an option to mitigate direct NH₃ emissions, with emphasis on mineral fertilization and machinery use. Maximum reductions of 10 and 13% were estimated for eutrophication and acidification respectively, with only marginal effects (from -1.3% to 4.2%) on the other impact categories. Inter-farm differences in impact per kg of protein produced and per m².yr of land occupation indicates that there are potential improvement possibilities to be investigated.

Keywords: milk, mitigation, farm gate, life cycle assessment

1. Introduction

Production of ruminant-based foods has been strongly criticized for its contribution to damaging emissions to the environment and resource use (Steinfeld et al. 2006). However at a global scale, it is expected that demand for these products will continue to increase (Alexandratos and Bruinsma 2012). Since resources are limited and damaging emissions have to be controlled, there is a need to improve cattle production systems. In Wallonia (southern Belgium), milk production is an important agricultural activity. Indeed, it accounts for 24% of the added value produced in Walloon agriculture (SPW-DAEA 2011). Walloon milk production tends to be intensive; specialized milk farms have a mean apparent N surplus of 189 kg/ha/y (CRA-W 2011).

Since agricultural activities are involved in most major environmental problems in Wallonia (e.g. acidification, surface water pollution, greenhouse gas (GHG) emissions; KIEW 2013), and to avoid transferring impacts between impact categories in mitigation proposals, a multi-criteria approach was used to estimate the environmental pressure exerted by dairy systems in southern Wallonia. Even though GHG emissions per unit of milk produced in Belgium are among the lowest in the world (Gerber et al. 2011), large variations are expected at a regional scale (Casey and Holden 2006), and it seems worthwhile to explore this variation to find mitigation opportunities at the farm level. Furthermore, the link between milk production, regional production potential, and sensitivity at the territory level has to be considered to optimize land occupation (e.g. use of non ploughable land for food production) and to avoid exceeding limits of local pressure on the environment.

Until now, multiple environmental impacts of milk production in southern Wallonia have not been estimated with life cycle assessment (LCA) methodology. LCA was applied using a tool called “Weden”, adapted from van der Werf et al. (2009), to 9 commercial farms located in a small territory (Gaume), and individual mitigation options based on improved manure application were proposed.

2. Methods

2.1 Goal and scope

The purpose of this work was to estimate environmental impacts of milk production by dairy farms in the Gaume region using an approach similar to that described by van der Werf et al. (2009). It is a one-year attributional cradle-to-farm-gate LCA that estimates environmental impacts of producing milk. The functional unit was 1 kg of fat-and-protein-corrected milk (FPCM; IDF 2010). The environmental impact categories considered were climate change (excluding land use and land-use change; IPCC 2006), eutrophication, acidification (CML 2013), cumulative energy demand (Hischier et al. 2010), ecotoxicity (USEtox 2013) and total land occupation (Hischier et al. 2010). System boundaries included main inputs and farm processes up to the farm gate, except for buildings and veterinary or cleaning products (Fig. 1). Waste disposal, destruction, or recycling were excluded. It was considered that imported animals and manure had no environmental burden but they were included in nutrient balance calculation. For all farms, classic technical indicators, such as N surplus and milk production per cow were also calculated to investigate improvement possibilities and their relation to environmental impacts. The target public was (1) farmers, to whom LCA results were reported along with technical indicators to investigate mitigation options mainly based on better manure application to land and (2) farm advisors, to consider LCA approaches for benchmarking and mitigating environmental impacts of cattle-based products at a small-territory scale (Gaume).

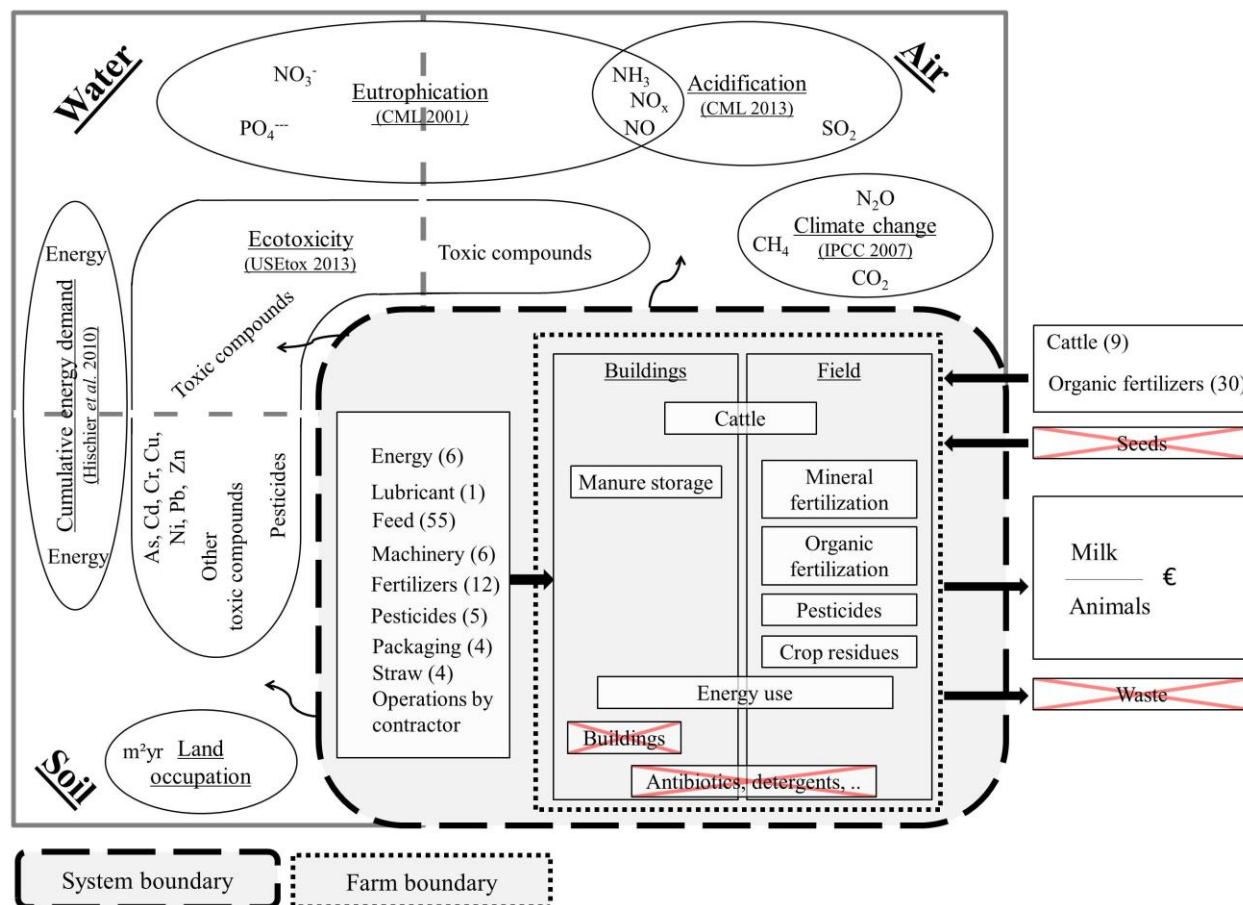


Figure 1. System description, impact categories and related damaging molecules and resources considered.

Numbers in parentheses indicate the number of items considered in the inventory after aggregation (e.g., 63 machinery alternatives recorded on farms were aggregated into 6 groups).

2.2. Dairy production in Gaume, farm descriptions and technical indicators

The Gaume territory is a cultural sub-region that covers two-thirds of the Jurassic region of Belgium and includes 372 km² of usable agricultural area (UAA). It was chosen for this study because of its homogeneous soil and climate conditions, production practices, and cultural characteristics (to allow sociological analysis of production systems in the Qualaiter project). In 2010, in the Jurassic region 7271 dairy cows on 132 farms (25% of all farms) produced a mean of 5500 l of milk sold/cow/yr (CBL 2013). Only 39 of these farms were specialized dairy farms without a suckling herd. Despite the fact that mixed systems are dominant in this region, specialized dairy farms were mainly chosen to avoid problems of allocation or boundaries between dairy and beef or crop production in mixed farms. Nine farmers agreed to participate in this study, and 8 of them were exclusively dairy farmers (two of them organic), while the ninth had 32 suckler cows along with 120 dairy cows. Overall, the 9 farms held 895 dairy cows or 19% of dairy cows in the Gaume territory (Table 3). For the only mixed system, information was collected from the farmer to separate both systems. When no data were available to segregate crop- and animal-production systems (e.g. agricultural area used as pasture) an allocation between systems was done according to animal-feed dry-matter requirements. Data were collected on farms for the 2012 calendar year.

2.3. The Weden tool, inventory and impact assessment

The Weden tool consists of an Excel® spreadsheet split into three sections: input data, calculations, and reporting. Weden estimates emissions from the following farm processes:

- cattle: CH₄ emissions from enteric fermentation
- feed: emissions from production and importation of feed and straw
- induced emissions: N₂O emissions due to on-farm NH₃, NO_x and NO₃⁻ emissions
- machinery: emissions for machinery production
- mineral fertilizers off- and on-farm: emissions from production and importation and emissions from on-farm fertilization, respectively
- energy off- and on-farm: emissions from production and importation of energy and lubricants and emissions from on-farm energy and lubricant use, respectively
- organic fertilizers on-farm: emissions in the barn, during storage and at application
- pesticides and plastics off- and on-farm: emissions from production and importation of pesticides and plastics and on-farm emissions of pesticides to land, respectively
- others: on-farm emissions from crop residues and surpluses of trace metals, NO₃⁻ and PO₄³⁻

Table 1. Identification and explanation of modules/data sources of the IPCC and EMEP models adapted.

Domain	Adaptation	Variable used	Direct influence on
Herd management	Herd distribution among 4 periods: in barn, always on pasture (excluding milking time), intermediate periods (in barn at night, outside during the day) before and after winter	Duration of periods, duration of presence in the barn for milking and intermediate periods	Manure distribution, animal energy and protein requirements, animal diet
N fixation	Estimated according to legume species in grasslands	Mean proportion of legume species in grassland cover in June	N balance
Animal	Diet quality for each period and each animal category	Feed supplied (amount and quality ¹) and grazed grass quality	N and methane emissions
	Performances and characteristics	Weights, liveweight gains, proportion of pregnant cow, carcass yield, milk production, lactation period	Nutrient balances, cattle requirements, meat production, milk production
	Milk-production dynamics	Main periods of calving and milking duration	Dairy cow energy and protein requirements during the 4 periods of the year considered
Buildings	Barn type per animal category	Type of barn	Manure type and nutrient content
Manure management	Type of machinery and time before incorporation into soil	Machine type and duration before incorporation into soil	Ammonia emissions

¹ Digestibility and crude protein content

Models used for the on-farm inventory are based on element balances (N, P, K and trace metals) at the farm level (van der Werf et al. 2009). Methane (CH₄) and nitrous oxide (N₂O) emissions are modeled according to IPCC (2006) Tier 2 except for soil N₂O (Tier 1). Ammonia (NH₃), and nitrogen oxide (NO₂ and NO_x) emissions were calculated with EMEP/EEA (2009) equations. Phosphorus emissions to water were estimated according to Nemecek and Kägi (2007) while the nitrogen surplus at farm level was considered as lost to water as nitrate. Inventories were based on farm data collected from bookkeeping, other official documents related to the EU Nitrate Directive (AGW 2011) or common agricultural policy and farmer interviews (ca. 3 hours long) for farm management (cattle diet, barn type, manure management, etc.). This was done to increase model sensitivity to farm management and/or characteristics (Table 1).

The cattle module was divided into the ten animal categories used for national statistics and farm bookkeeping based on animal age and function (dairy vs. suckler cow). For each, animal requirements and excretion were calculated from IPCC Tier 2 (2006) based on diet quality, animal characteristics and management. If these were not available, data were taken from default values found in the literature (Table 2). Three manure types were considered: slurry, semi-solid manure and farmyard manure. Emission factors from IPCC (2006) used for semi-solid manure were those of solid storage and those for farmyard manure were those of storage below animals, according to emissions observed by Mathot et al. (2013). The Weden tool was also developed to take into account regional variability in machinery, barn types, manure management, pesticides, crop yield and characteristics, and organic and mineral fertilization (Table 2). Based on a detailed list of 279 machines (Mecacost tool: Rabier et al. 2008), details given by farmers about annual use (converted to kg machine equivalent), and the corresponding inventory, emissions of 6 categories of machines (general, tillage, harvester, tanks, tractors and trailers; Frischknecht et al. (2013)) were estimated. Consumption of fuel for operations by contractors was estimated according to Rabier et al. (2008) and expert opinion (F. Rabier, Pers.comm. 2013) for the choice of representative equipment and use. Inventories for the production of pesticides (5 types), mineral fertilizers (12 types), energy sources (6 types), lubricant (1 type), and plastics (4 types) were obtained from Frischknecht et al. (2013) and detailed data from farmer interviews and regional product lists and characteristics when necessary (Table 2). Inventories of feed and straw production were adapted mainly from Blonk et al. (2009), Frischknecht et al. (2013) and Piazzalunga et al. (2012).

Table 2. Main data sources for inventory and modeling of emissions

Item	Primary sources
Nutrient contents of slurry, semi-solid manure, farmyard manure and types of organic matter	AGW 2011; Godden et al. 2013;
Nitrogen fixation by legumes in grasslands	Limbourg et al. 2001
Machinery characteristics and fuel consumption	Rabier et al. 2008
Trace metal balance and content	Li et al. 2005; Piazzalunga et al. 2012
Cattle characteristics	INRA, 2007
Plant yield and characteristics; feed composition	CVB 2010; INRA 2007
Animal product characteristics	Mathot et al. 2012;
Mineral fertilizer characteristics	Piazzalunga et al. 2012
Pesticides	SPW-DAEA 2012
Packaging	van der Werf et al. 2009

Emission factors for eutrophication (PO₄eq), acidification (SO₂eq) and climate change (CO₂eq) were identical to those used by van der Werf et al. (2009). Cumulative energy demand (MJ) was calculated using characterization factors of Frischknecht et al. (2007). For ecotoxicity (CTUe), emissions of all toxic compounds included in the ecoinvent v2.2 inventory database (Frischknecht et al. 2007) were included for inputs, using USEtox characterization factors (USEtox 2013). On-farm emissions of trace metals, products of combustion and active ingredients of pesticides were included. A simplified approach was used for active ingredients of pesticides: we assumed that all active ingredients applied were emitted to soil. A list of currently applied products (467) and their active-ingredient concentrations (239) was obtained from SPW-DAEA (2012). When available (ca. 75% of pesticides), characterization factors from the USEtox database were used (not shown). When not known, the mean characterization factor of all active ingredients was used (486 CTUe/kg).

Per farm, one mitigation option to decrease NH₃ emission was simulated taking into account a better manure management by application of slurry with trailing hose instead of a splash plate and rapid incorporation of solid

manure (UNECE 2007). A change in spreading equipment (tractor and tank/spreader) was included based on Rabier et al. (2008). Regardless of the mitigation option, and according to simulation with the Mecacost tool (Rabier et al. 2008), fuel consumption did not increase due to the use of more efficient spreading equipment (suitable power and faster operations). Mineral N fertilization was also reduced by assuming a ratio of 1 kg N per kg of N-NH₃ not lost during organic fertilizer spreading.

2.4 Uncertainty analysis and interpretation of results

Sensitivity to the type of allocation method used for co-products (meat and milk, no plant production was sold) was tested by comparing results from economic, biophysical (IDF 2010) and protein allocation. The latter two allocation methods were calculated using the change in animal numbers after subtracting imported animals, while for economic allocation, neither changes in animal numbers or purchases were included. Statistics were performed with R software (R Development Core Team 2011). For each farm, a summary of the results was produced, including comparison with those of other farms. The summary included results about the technical indicators, impact on the environment per kg of FPCM and per m² of UAA, and distribution of environmental impacts between on- and off-farm activities and within the farm. Furthermore, opportunities for mitigation were discussed based on manure management while using more efficient machinery to avoid NH₃ losses at spreading. Partial results and technical indicators (Table 3) were used to validate data collected and results. To investigate links between production efficiency and land-use intensity, the relation between impacts per m² of land occupation and impacts per kg of total protein produced was analyzed. Total protein was used as indicator to include meat production.

3. Results

Using economic allocation, mean (standard deviation (SD)) emissions per kg of FPCM for the 9 farms were 254 (116) g CO₂, 1.04 (0.2) g N₂O, 8.3 (1.71) g NH₃, 2.27 (0.38) g NO, 0.88 (0.36) g NO_x, 0.54 (0.2) g SO₂ and 32 (6) g CH₄ to air and 0.01 (0) g NH₃, 39 (39) g NO₃⁻, 1.11 (0.83) g PO₄³⁻ to water. Due to the large number of active ingredients involved in ecotoxicity, it was not possible to disaggregate them. Mean environmental impacts for the production of 1 kg of FPCM were 8.5 (4.5) g PO₄eq, 15.5 (2.8) g SO₂eq, 1.4 (0.2) kg CO₂eq, 3.0 (2.9) CTUe, 3.8 (1.2) MJ and 4.6 (0.7) m².y for eutrophication, acidification, climate change, ecotoxicity, CED and land occupation, respectively (Fig 2.1-2.6), with economic allocation between milk and meat production. High variability was observed for all impact categories (coefficient of variation = ca. 10-100 %, Fig. 2.1-2.6). Changing the allocation method to biophysical or protein-based allocation (Table 3) reduced impacts of milk production by 11% and 4%, respectively. However, there were no relations between economic and biophysical or protein allocations ($p > 0.05$, $r = 0.225$ and $r = 0.178$, respectively), though protein and biophysical allocations were significantly correlated ($p < 0.001$, $r = 0.997$).

For eutrophication, acidification, climate change and land occupation, on-farm emissions dominated (>70%), while for CED and ecotoxicity off-farm emissions dominated (>60%). Organic matter management (storage and application) was, on average, a main contributor to eutrophication (46% (30%)), acidification (84% (7%)) and climate change (22% (3%)). However, the main contributor to climate change was the herd, through CH₄ emissions from enteric fermentation (48% (8%)). For ecotoxicity, feed production contributed 65% (20%), while pesticide production and application contributed 9% (10%).

The main source of N fertilizer was organic manure. Indeed, 51.4% (17%), 8.6% (13%), 5.2% (10%) of N fertilized originated from slurry, farmyard manure and semi-solid manure, respectively, while the remaining 35% (26%) came from mineral fertilizers. On average, 87% (6%) of NH₃ emissions were due to organic manure management, with 34% (6%), 30% (4%) and 36% (10%) of them were emitted in the barn, during storage and spreading on the soil, respectively. Considering the equipment for and management of solid and liquid manure

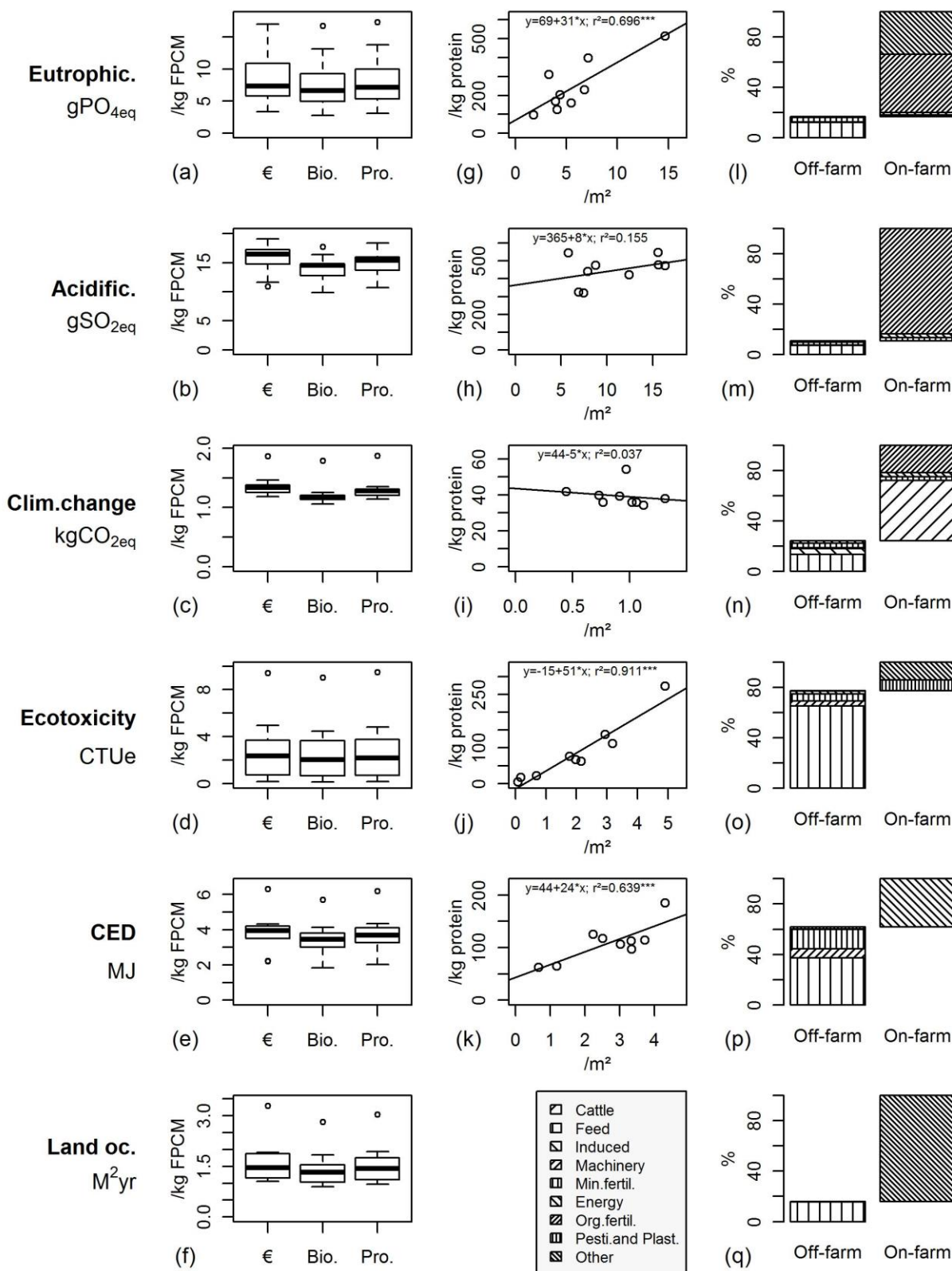


Figure 2. Potential environmental impacts per kg of fat-and-protein corrected milk (FPCM) as a function of allocation method (2.1-2.6): economic (€), biophysical (Bio.) and protein (Pro.), boxplots according default parameters. Relations between impact per m² of land occupation and that per kg protein produced for the 9 farms (2.7-2.11); *, ** and *** indicate p<0.05, p<0.01, and p<0.001, respectively. Distribution (2.13-2.17) of the environ application to land, there was an opportunity to mitigate of NH₃ emissions and consequently N fertilizer use for

7 farms (Table 3). Simulation of these mitigations led to a decrease of 26% (6%) of NH₃ emission at application and, consequently, with a change in equipment and reduction of mineral fertilization, to reductions of 4.8% (3.6%) and 8.4% (2.6%) of eutrophication and acidification impact, respectively. Marginal positive effects were also observed for the other impact categories (climate change: 0.4% of CO₂eq, ecotoxicity: 6% CTUE and CED: 0.7% of MJ), but an increase was observed for the farms without mineral N fertilization (Table 3). mental burden: off- (left) and on-farm (right) and, within each, origin of the impact.

For eutrophication, ecotoxicity and CED, significant positive correlations were observed between impacts per kg of protein produced and per m².y used (p<0.05). No correlation was observed (p>0.05) for the other impact categories (Fig. 2.7-2.11).

Table 3. Mean characteristics, technical indicators, allocation factors and results of mitigation options for all 9 farms studied

Category	Item	Unit	Mean	SD	Max	Min
On-farm area	Total	Ha	94	41	159	55
	Grasslands	%	73	14	96	53
	Silage maize	%	17	15	35	0
	Other crops	%	10	8	27	0
Herd	Total	Number	197	62	334	117
	Dairy cows	Number	99	37	175	42
	Head not dairy cows/head dairy cows		1.05	0.30	1.80	0.74
	First calving age	Month	31	5	36	25
	Livestock units (LU) ¹	LU/ha/year	2.4	0.6	3.2	1.2
Milk production	Total	10 ³ kg milk	733	365	1559	299
	Without milk for veals	10 ³ kg milk	688	352	1493	270
	Per dairy cow per year	kg milk	7461	1309	9188	5373
	Production duration/calving interval	%	84	3	89	80
	Fat concentration	g/kg milk	40.1	1.8	43.2	37.5
	Protein concentration	g/kg milk	33.4	1.6	35.2	31.0
Meat production	Live weight produced	10 ³ kg	20.0	6.2	27.8	11.2
	Protein produced	10 ³ kg	3.00	0.93	4.17	1.68
Balance ²	N surplus	g N/m ²	14.1	8.7	33.4	5.0
	N fixation	g N/m ²	2.97	1.67	5.89	1.05
	N inputs in feed and fertilizers	g N/m ²	57	31	116	20
	N fertilization ³	g N/m ²	17	10	31	4
	NH ₃ losses during manure fertilization	g N/m ²	1.92	1.12	3.69	0.69
	P surplus	g P/m ²	1.60	1.57	3.92	-0.98
Impact allocated to milk	P inputs in feed and fertilizers	g P/m ²	2.78	1.48	5.03	0.80
	Economic	% of € from milk/ € revenue	91	2	95	88
	Protein-based	% of kg protein sold as milk /kg protein produced	88	3	93	82
Mitigation ⁴	Biophysical		82	5	89	73
	NH ₃ emissions	% N lost as NH ₃	26	6	33	17
	Eutrophication	%	4.8	3.6	9.7	1.0
	Acidification	%	8.4	2.6	12.5	4.5
	Climate change	%	0.4	0.3	0.8	-0.3
	Ecotoxicity	%	0.6	1.7	4.2	-1.2
	Cumulative energy demand	%	0.7	1.3	1.8	-2.0
Land occupation	%	0	0	0	0	

¹ According to Stilmant et al. (1998). ² At the farm scale, related to the usable agricultural area of the farm. ³ Organic and mineral fertilization at spreading (before NH₃ losses from manure). ⁴ Percentage reduction for the 7 farms considered for mitigation.

4. Discussion

Although comparing results of this study with those from the literature is difficult because of methodological differences, we estimated higher values than those reported by Nguyen et al. (2013) for eutrophication (+60%) and acidification (+33%), similar values for climate change (-4%) and land occupation (+10%) but smaller values for CED (-14%). For eutrophication and acidification, differences could be explained in part (<10%) by high NH₃ emissions due to the low efficiency of equipment used in 7 of the farms. For eutrophication, 260 (300) g PO₄eq came from NO₃⁻ emissions of 14.1 (8.7) g N/m², higher than those in a similar study (8.1 g N/m²; van der Werf et al. 2009), which could help to explain the high eutrophication impact estimated. However, too little information was available for a full comparison with Nguyen et al. (2013), who did not calculate NO₃ emissions using farm-gate N balances. Furthermore, our small sample size means that extreme values can greatly influence mean values. When reporting results to farmers, environmental impact, technical information and mitigation possibilities (Table 3) were discussed with a particular attention to extreme values, like for nitrogen surplus, to investigate other mitigation options than those concerning manure management. As no environmental burden was attributed to imported animals, impacts are underestimated. However, for the 9 farms considered animals were imported on only one farm (2% of the herd), thus the underestimation is certainly relatively small.

The allocation method also influenced impacts of milk production, attributing fewer impacts to milk when shifting from economic to protein-based to biophysical allocation. Attributional LCA remains problematic due price fluctuations impact on economic allocation or more generally the choice of allocation methods that may change distribution of impacts between meat and milk. For product labeling, attributional approach seems necessary (e.g. IDF 2010); however, the use of functional units that require no allocation between co-products at the farm level, such as protein production (van Dooren et al. 2014), could be used to assess improvement in food production. Consequential LCA or system expansion could also be used.

Considering total protein production (milk and meat), improvement may be achieved by adopting the mitigation option of improving manure application to land or management. Simulation of the former, even though based on simple models, decreased environmental impacts (by 0.4-8.3%). The simulation assumed a reduction of N mineral fertilization directly proportional to the decrease in NH₃ emissions. This assumption is open to criticisms in the short term at least due to farmers' fears of quality or yield losses and higher costs due to change in machinery or energy purchase. Since NH₃ emissions from organic fertilization strongly influence eutrophication and acidification impacts, higher reductions could be expected if more efficient equipment was used (e.g. manure injection; EMEP/EEA 2009). This possibility was not tested because it would have involved major changes in equipment and energy use, reducing the chances that farmers would adopt the mitigation option. Furthermore, no reduction in mineral fertilization was possible in organic systems, which do not use it. Thus, only changes in machinery were taken into account, leading to marginally higher emissions for other impact categories (negative values in Table 3). This problem reflects difficulties in predicting changes in the quantity and quality of potentially available N for plant production and the related milk production, which was not predicted in simulations.

For mitigation associated with changes in farm management, even though only a few farms were considered, the positive relation between impact per kg FCPM and per m² of land occupation estimated for eutrophication, ecotoxicity and CED should be investigated further. Indeed, this relation indicates that it is feasible to have relatively low impact per unit of product and per unit of land occupied. Indirect emissions contributed strongly to ecotoxicity and CED, while direct emissions (N and P surpluses) contributed strongly to eutrophication (Fig 2.12, 2.15 and 2.16). Therefore, the relation between feed inputs and animal production (milk and meat) seems to be a key factor to adjust to reduce environmental impacts. However, on-farm land occupation is quite high (0.842 (0.098) m²/total m²), reflecting the importance of on-farm cattle feed production and of milk production linked to the territory, which is composed mainly of grasslands (0.731 (0.142) m²/m² of on-farm land occupation). Other mitigation options can be proposed based on technical indicators such milk production, herd composition or age at first calving. The complexity of production systems at the farm scale, however, makes it difficult to render good advice about practices. For example, to reduce the ratio of non-productive to productive animals, which varies widely between farms (coefficient of variation = 30%, Table 3), one could recommend reducing the age at first calving. However, one consequence of this change could be an increase in the amount of concentrated feed in the diet of young cattle, which could increase environmental impacts but also decrease veal production. Less veal production would have potential consequences, such as, in a consequential LCA approach, increased veal production in other systems to satisfy demand for veal.

Finally, the variability observed highlights the diversity and thus room for improvement in these production systems, even in a small and relatively homogeneous area. Methodological problems, however, such as errors in the inventory are still possible due to missing or incorrect data collection or modeling. Therefore, validating results and/or improving models are necessary. For example, in this study the complete causal chain recommended by IPCC (2007) and EMEP/EEA (2009) for cattle feeding was included, from feed ingestion to manure application to soil. However, the causal chain for N emissions probably depends greatly on the quality of the diet used in the inventory. Ideally, feed input, feed stock change and, when available, forage analysis in diets included in the study have to be validated. Results such as mean N (excretion – losses in the barn and storage) and CH₄ production by cattle (105 (21) kg N and 130 (13) kg CH₄ per dairy cow per year, respectively) have to be compared to regional recognized referential values. Furthermore, in the future, default values in causal chains should be replaced with better data, for example, by improving knowledge about cattle nutrition or estimating enteric CH₄ emissions at the farm scale with estimation based, for example, on milk analysis (Dehareng et al. 2012). However, this last approach will not solve the problem of modeling GHG emissions of non-milk-productive animals, which requires additional measurement (Mathot et al. 2012). Finally, beyond the normative approach, improvement and mitigation strategies have to be identified.

5. Conclusion

Despite the small number of farms studied, environmental impacts of milk production in the small territory of Gaume was highly variable. Implementing good practices such as using better manure spreading methods may mitigate eutrophication and acidification impacts. Further research is required to investigate and model differences in farm inputs and production, including both milk and meat co-products.

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