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LIFE CYCLE ASSESSMENT OF DAIRY PRODUCTION SYSTEMS IN SWITZERLAND: STRENGTHS, WEAKNESSES AND MITIGATION OPTIONS

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Abstract

The dairy sector is the most important agricultural sector in Switzerland, contributing over 20% to the economic return of Swiss agriculture. Over 70% of Swiss agricultural area consists of grassland, without counting the vast Alpine pastures. In this paper we present results from four LCA studies in the Swiss dairy sector.

We analysed the environmental impacts of Swiss dairy farms during three years by means of LCA, leading to the following conclusions: The environmental impacts per kg of milk vary widely between farms. These differences can only partly be explained by factors such as region (lowlands, hills and mountains), farming system (integrated or organic) or farm type. The environmental impacts per kg of milk tended to increase in the higher altitudes, due to less favourable production conditions (steep slopes, lower grass yields, longer winter feeding period). Increasing milk production per farm was related to a slightly lower global warming potential (GWP). Organic farms had lower ecotoxicity impacts, thanks to the ban of synthetic pesticides.

The comparison of Swiss dairy production to the neighbour countries Germany, France and Italy showed that the environmental impacts of Swiss milk and cheese were generally lower or similar than imported cheese, despite the 2-3x lower input of concentrate feed in Switzerland. The result was explained by the relatively good conditions for grass growth, allowing to produce large amounts of high quality roughage and to achieve good milk yields with modest inputs of concentrates.

The full grazing system with block calving was compared to a total mix ration system in Switzerland. It had a lower energy demand, acidification and eutrophication potentials, ecotoxicity, resource consumption and deforestation, mainly due to lower concentrate inputs. On the other hand, the land occupation of the full grazing system was higher, due to lower yields and higher feed consumption. Furthermore, GWP and ozone formation were increased due to higher methane emissions.

Several mitigation options for the reduction of greenhouse gases (GHG) and other environmental impacts were analysed recently. The increase of the number of lactations per cow from 3.5 to 4.5 led to a general decrease of environmental impacts and was therefore one of the most promising GHG mitigation measure on Swiss farms.

Introduction

This paper presents lessons learnt from several life cycle assessment (LCA) studies in the Swiss dairy sector. It starts with a brief overview of Swiss dairy production and processing, followed by a short introduction to the LCA methodology. Then, results from two studies on milk production in Switzerland and neighbouring countries are presented, including cheese manufacturing. Next, an experiment with a barn-fed herd and relatively high milk yield with a full-grazing herd and lower milk yield is compared by LCA. Finally, selected results of a study on GHG mitigation measures on Swiss farms are reported, before coming to the conclusions and outlook.

The Swiss dairy sector

The area of Switzerland amounts at 4.1 mio. ha, two third lies in mountain areas. 1.05 mio. ha is agricultural area with 71% of permanent grassland (BFS, 2015); additionally 0.5 mio. ha are Alpine pastures. Grassland is therefore the predominant type of agricultural land use. In 2014, the dairy sector contributed 22% to the production value of Swiss agriculture. The food self-sufficiency of Swiss agriculture lay at about 60%, so that imported food is of high importance.

In 2014, 1.6 mio. heads of cattle were living in Switzerland, of it were 0.6 mio. dairy cows (mainly Brown Swiss and Holstein). They were held by 35,000 dairy farmers, which means on average about 20 cows per farm, with an average milk yield of 6970 kg per cow and year. The mean farm size was about 20 ha (SBV, 2014).

4.1 mio. tons of milk were produced with 4.1% fat and 3.3% protein. They were transformed to 44% cheese (of which $^{1}/_{3}$ was exported), 17% butter, 12% fresh milk, 11% milk powder, 8% cream, 3% yoghurt, and 8% other dairy products.

LCA methodology

Life cycle assessment is an environmental management tool with two main characteristics:

- The *consideration of the full life cycle*. Processes are included from the extraction of the raw materials (resources) to the disposal of the waste or to a defined state or location, such as the farm gate or the point of sale. Including the life cycle aims at avoiding the displacement of environmental burdens to other phases, in contrast to methods looking at the farm only.
- The *consideration of all relevant environmental impact categories*. By this, a shift of the environmental burdens from one environmental impact to another should be avoided. Typical impact categories include the use of abiotic resources, such as energy or the mineral resources P and K, water use, land use, climate change, eutrophication, acidification, ozone formation, ecotoxicity and human toxicity, but also biodiversity and soil quality for agricultural systems.

The principles of LCA are described in ISO standards 14040 and 14044 (ISO, 2006a, b), which define four phases:

1. In the goal and scope phase the framework of the study is designed. This encompasses e.g. the functional units (reference flows), the system boundaries, the allocation rules, data quality considerations, and the choice of the environmental impact categories to be considered.

2. In the life cycle inventory (LCI) phase an inventory of all production data, emissions and resources used is established over the whole life cycle.
3. The life cycle impact assessment (LCIA) phase aims at summarising the large emission and resource inventory to a few impact categories to allow an interpretation.
4. Finally, in the interpretation phase, all results are analysed in order to derive conclusions and recommendations.

The Swiss Agricultural Life Cycle Assessment (SALCA) methodology is developed at Agroscope since 2000 (Gaillard & Nemecek, 2009; Nemecek *et al.*, 2010). SALCA consists of the following components:

- *Database* for life cycle inventories for agriculture. The database is developed in close co-operation with *ecoinvent* (especially regarding data format and quality criteria), which makes the agricultural inventory data compatible with all the other economic sectors. Agroscope is one of the founding member of the ecoinvent centre.
- *Models* for the calculation of direct emissions from field and farm. The non-linearity inherent to agricultural processes requires for a credible environmental assessment the consideration of specific models for direct emissions. Together with environmental scientists in their respective discipline, we developed or adapted models for the most current emissions encountered in agriculture, such as ammonia, nitrate, nitrous oxide, phosphorus, or heavy metals.
- A *selection of impact assessment methods.* The impact assessment methods developed by the scientific community mostly are not focused on agriculture. A major support is to assess and select a set of impact assessment methods appropriate for agricultural applications.
- Methods for the assessment of impacts on *biodiversity* and *soil quality*. We developed two methods in order to cope with the environmental impacts commonly summarised under the expression “land use”: SALCA-biodiversity (Jeanneret *et al.*, 2014) and SALCA soil quality (Oberholzer *et al.*, 2012).
- *Calculation tools* for agricultural systems (farm, annual crop, perennial crop). To assess the variability of agricultural production systems and site conditions, a large number of LCA calculations is needed. For this purpose automated tools are required with a coherent system analysis for consistent comparisons. We developed calculation tools for some archetypical cases (like farm, crop) based on a commercial LCA software (Nemecek *et al.*, 2010).
- *Interpretation schemes* for agricultural LCA. Especially for stakeholders not currently dealing with environmental information like delivered by LCA, it is central to integrate environmental results delivered by the tools in such a way that they can be used by the stakeholders. An example of it is the interpretation and communication concept for environmental farm management.

A typical system description of a dairy production system at farm is presented in Fig. 1.

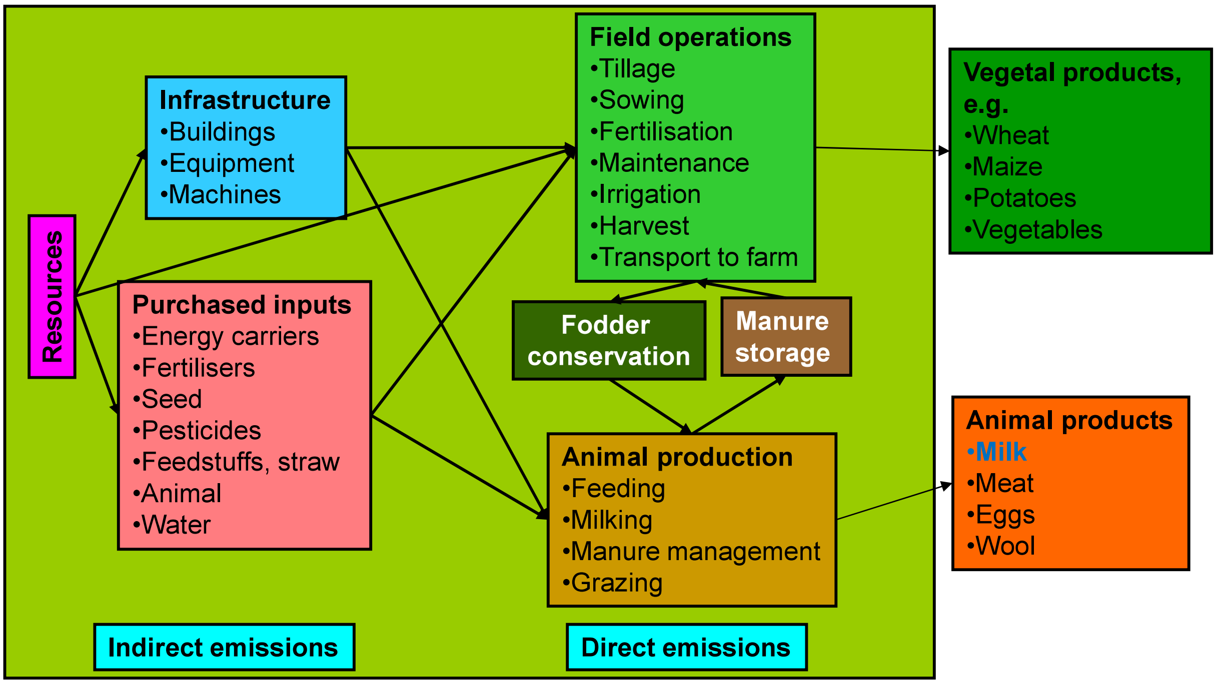

Fig. 1: System description of a milk production system at farm. Since several products are produced by a single farm, allocation or system expansion is necessary, in order to analyse the dairy production.

Examples of studies in the dairy sector in Switzerland and neighbouring countries
LCA-FADN project: assessment of a pilot farm network
The objective of this project, supported by the Swiss Federal Office for Agriculture, was to evaluate the environmental performance of Swiss farms by means of LCA. Farms were selected according to a stratified sampling plan by considering the farm type, the region (lowlands, hills, and mountains) and the farming system (integrated and organic) during the years 2006 to 2008. A total of 110 farms was analysed, of it were 66 dairy farms. The products were aggregated into 14 product groups, covering all types of products (plant products, animal products and non-food products). Here we will summarise the main results for the milk production. The full results can be found in Hersener *et al.* (2011) and Alig *et al.* (2011).

A high variability of the environmental impacts between the farms has been found. This variability could only partly be explained by the region, the farm type or the farming system. It has been concluded that the individual management and the organisation of the farm are highly relevant for the environmental performance of the farm and that a large optimisation potential exists.

The energy demand and the global warming potential increased significantly with higher altitudes (Fig. 2). This was explained by the more difficult conditions for dairy production in the mountains: lower grass yields, which required the management of a larger area to achieve the same yields, steeper slopes resulting in a higher fuel consumption and the need for specially adapted machinery, longer winter feeding period and consequently a higher need for fodder conservation, and farms with a smaller milk production. The variability within one group also increased with the altitude. Some small farms in the mountain areas had a high energy demand and global warming potential, while other small farms in the same area performed much better.

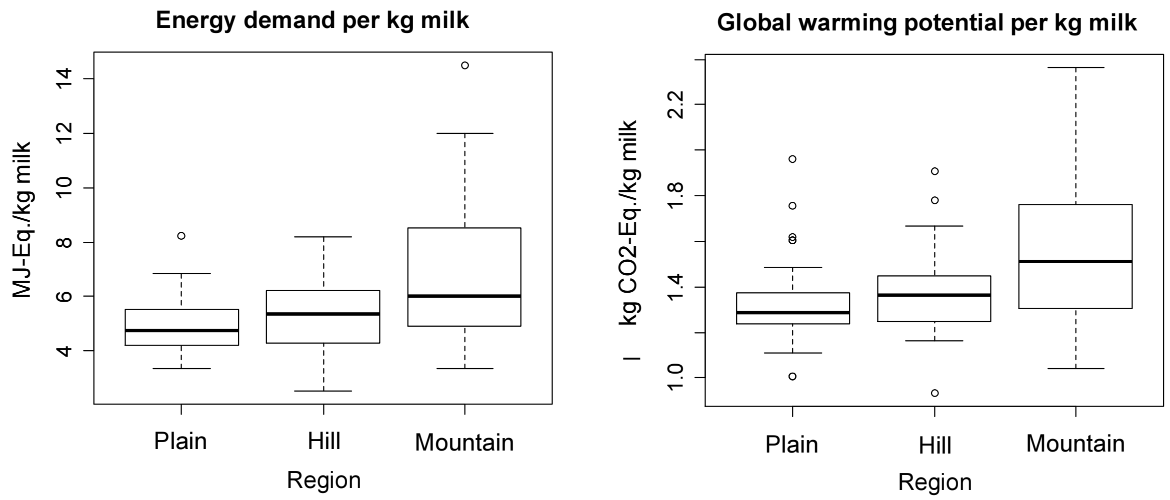

Fig. 2: Energy demand and global warming potential for Swiss dairy production in the plain (lowland), hill and mountain regions.

For eutrophication no significant differences were found. Factors leading to higher nutrient (N & P) losses like steeper slopes (leading to erosion), higher precipitations (leading to higher leaching), or larger areas to be managed were compensated by factors reducing emissions, such as cooler and wetter climate reducing ammonia volatilisation and the larger proportion of grassland, which is less prone to nitrate leaching.

Ecotoxicity potentials were significantly lower in the mountains. As grasslands are generally not treated by pesticides, the impacts come mainly from arable crops for feed production.

No significant differences were found between organic and conventional milk, with the exception of ecotoxicity, which was clearly lower for organic milk due to the ban of pesticides.

The contribution analysis showed that on average the impact categories were dominated by the following input groups:

- Energy demand: energy carriers (31%), purchase of feedstuff and buildings/equipment (both 17%)
- GWP: emissions from animal husbandry (59%) and additionally CO_2 from the same input groups contributing to the energy demand
- eutrophication: manufacturing of fertilisers and direct emissions from their application (45%), emissions from animal husbandry (23%), purchase of feedstuffs (14%)
- ecotoxicity: purchase of feedstuffs (58%) and pesticide applications on farm (20%).

Comparing Swiss cheese from cow milk to imports

The study "Life cycle assessment of selected Swiss agricultural products compared to imports" aimed at comparing products originating from Swiss agricultural production to imports. Cheese from cow milk, beef, bread from wheat, potatoes and feeding barley were analysed. The study was supported by the Swiss Federal Office for Agriculture. Full results of this study can be found in Bystricky *et al.* (2014), Bystricky *et al.* (2015) and Alig *et al.* (2014); here we present results for cheese.

The dairy production systems differ between the investigated dairy productions (Table 1). Note that for Switzerland an average production was assessed, while for the neighbouring countries typical, widespread system were considered, since it was not possible to analyse the range of variation of the systems in each country. Swiss dairy production has lower milk yields and lower inputs of concentrates, while it is characterised by a high share of roughage and more frequent grazing.

Table 1. Production parameters of the milk production systems in Switzerland (Milk CH), Germany (Typ. Milk DE), France (Typ. Milk FR) and Italy (Typ. Milk IT). DM: dry matter, FM: forage mixture, BR: basic ration. Typ. = typical.

Parameter	*Unit*	Milk CH	Typ. Milk DE	Typ. Milk FR	Typ. Milk IT
Number of dairy cows		19.9	80	46	419
Age of first calving	*months*		28	29	27
Useful life	*months*	40	37.7	32.9	21
Restocking	*%*	30	36	37	37
Calves born alive	*calves*year^{-1}*	0.9	0.9	0.83	0.9
Barn arrangement		50% free stall barn	50% free stall barn	100% free stall barn	100% free stall barn
Milk yield	*kg*cow^{-1}*year^{-1}*	6,800	8,000	8,200	9,450
Milk production	*kg*farm^{-1}*year^{-1}*	127,372	600,000	369,000	3,721,026
UAA for milk production	*ha*	0.58	0.6	0.84	0.51
Pasturing	*days*year^{-1}*	167	-	112	-
Feed intake	*kg DM*cow^{-1}*day^{-1}*	20.2	19.6	20.4	18.0
Concentrates	*kg DM*LU^{-1}*year^{-1}*	877 *25% FM dairy* *75% FM cereal*	2,019 *33% wheat* *33% barley* *25% soya* *8% rape meal*	2,164 *47% soy meal* *41% wheat* *8% FM conc.* *4% FM min.*	2,498 *35% maize flour* *23% soy meal* *15% cotton seed* *13% protein supp.* *10% soy seeds* *4% maize flakes*
Basic ration	*kg DM*LU^{-1}*year^{-1}*	6,752 *41% grass silage* *29% grass* *19% hay* *11% maize silage*	5,100 *56% grass silage* *37% maize silage* *12% hay*	5,804 *62% maize silage* *26% grass* *9% grass silage* *3% hay*	4,068 *60% maize silage* *39% hay* *1 % grass*
Share of basic ration in total ration	%	89	72	76	62

Selected results are shown in Fig. 3. Overall cheese from Swiss production had lower or similar environmental impacts than imported cheese and this was mainly due to the dairy production at farm, as cheese processing, storage, transport and retail were of minor importance.

The impact on deforestation of Swiss cheese was much lower, since only little soybean meal is fed and if used, it mainly originates from certified production, which does not come from deforested areas. The water stress index was also much lower, since the higher precipitations in Switzerland allow to produce with little or no irrigation.

The study showed that no simple relationship between amount of concentrates, milk yield and environmental impacts exists; instead the results depend on the whole production system. Site conditions can influence the environmental impacts significantly: In Switzerland, the good growing conditions for grassland with abundant precipitation and a high quality of roughage allow to produce milk at moderate intensity level with small amounts of concentrates in an efficient way.

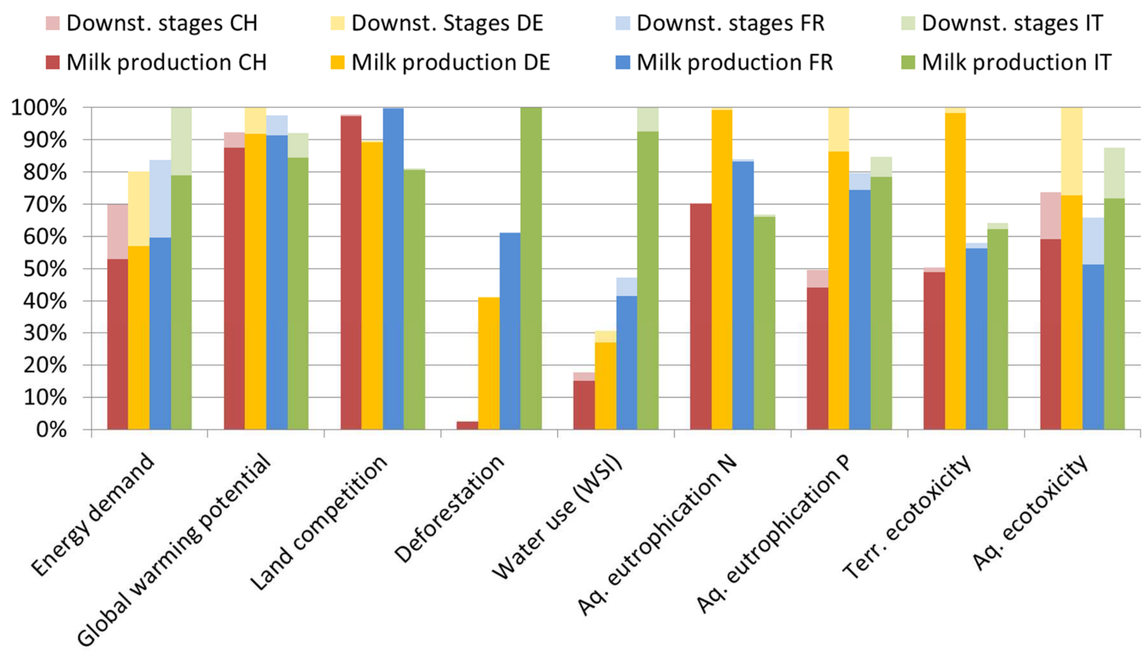

Fig. 3: Selected environmental impacts per kg of cheese originating from different countries at the point of sale in Switzerland. CH = Switzerland, DE = Germany, FR = France, IT = Italy.

LCA of different Swiss dairy production systems (full grazing vs. barn feeding)

An experiment comparing a relatively intensive barn feeding system with a full grazing system at the Hohenrain experimental farm in Central Switzerland was carried out during the years 2008 to 2010. A comprehensive LCA study of these systems was conducted using the SALCA method. Table 2 shows the characteristics of the two herds, Fig. 4 the main results. For further information and the full results see Sutter *et al.* (2013).

Table 2: Characteristics of the dairy production systems in the Hohenrain experiment.

	Barn feeding	**Full grazing**
	24 cows	28 cows
Milk yield	8,900 kg	6,100 kg
Grazing	Daily for 1-2 h	24 hours mid March-beginning Nov.
Concentrates	1,100 kg/cow/year	300 kg/cow/year
Feed	Maize/grass silage Protein concentrates	Ventilated hay
Calving	All year	February-April

The full grazing herd was mainly fed by grass and received less concentrates, which resulted in a lower ecotoxicity (since pesticides are mainly applied to arable crops to produce feed), less P & K resource use and less deforestation, since only little soybean meal was used. The effect of grazing could be observed in lower ammonia emissions and therefore a lower acidification potential. On the other hand was the full grazing herd less efficient. It used 0.93 kg feed dry matter per kg of energy corrected milk (ECM), while the barn-fed herd used 0.78 kg only. This resulted in higher methane emissions from enteric fermentation, with consequently higher global warming and ozone formation potentials. In addition, more land was used to produce the feed, which however, mainly consisted of grassland, while the area of arable land was lower.

Finally, the full-grazing herd had a higher biodiversity potential, since grazing creates more heterogeneity in grassland than grass cutting.

Several impacts decreased over the three experimental years in the newly introduced full-grazing herd, showing that this system has a large improvement potential.

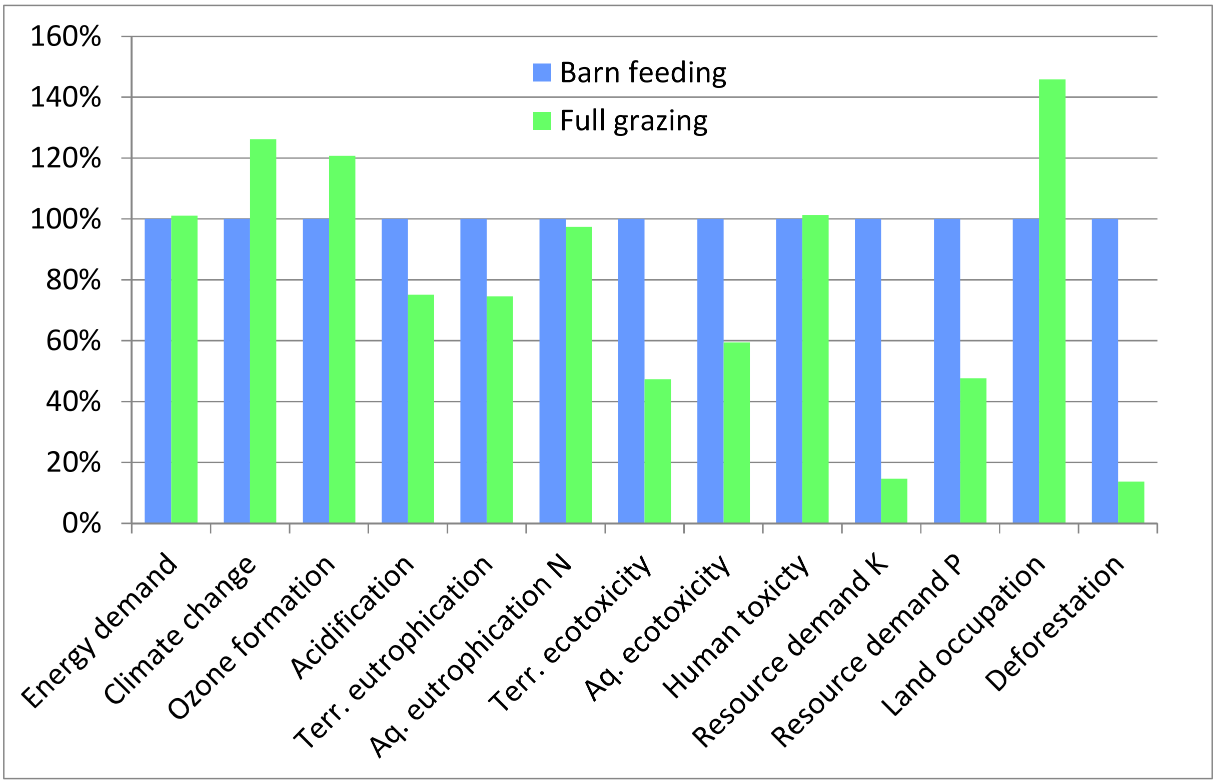

Fig. 4: Relative impacts per kg of ECM of the two dairy production systems in the Hohenrain experiment 2008-2010. The higher of the two values corresponds to 100%.

Evaluation of GHG mitigation measures

Accounting for around 10 %, agriculture contributes significantly to Switzerland's greenhouse-gas emissions. This project was mandated by the farmer's organisation IP-SUISSE, with the objective to provide the scientific basis for developing a Climate Protection point system for IP-SUISSE farms. To this end, promising climate-protection measures with high greenhouse-gas-reduction potential and feasibility were selected and described, with the aim to improve the greenhouse-gas efficiency of farms. In addition, the greenhouse-gas-reduction potential of all selected measures, including potential synergies and trade-offs with other environmental impacts, was determined by means of a LCA.

The quantity of digestible energy (dE) produced by the farm as a whole was used as a reference unit representing productivity, in order to illustrate greenhouse-gas efficiency, i.e. the environmental impact per produced dE. The impact of a measure was calculated for the four model farms 'field crops', 'commercial milk', 'other cattle' and 'pigs'. For more information see Alig *et al.* (2015).

Here we present the results for the increase of number of lactations per cow. Currently, dairy cows in Switzerland have only 3.5 lactations on average during their lifetime. An increase to 4.5 lactations is considered as a realistic option, without negatively affecting the productivity. This would lead to a reduction of GHG emissions of 4.5% in the dairy farm, and lower reductions in the other farms, since they have a lower number of dairy cows. No trade-offs were observed for the other environmental impacts. Therefore this measure can be recommended based on this study.

Conclusions

An important environmental improvement potential has been identified for Swiss farms, and dairy farms make no exception to this. Swiss cheese has shown to have lower or similar impacts than imported cheese, which was due to favourable conditions for grass growth in Switzerland, allowing to achieve high grass yields with good quality and therefore to produce milk with low amounts of concentrates. Grassland-based and pasture-based systems have environmental advantages, but their productivity must be improved to achieve a favourable environmental profile. Finally, increasing the number of lactations per cow has shown to be effective to reduce GHG emissions and other environmental impacts.

LCA has proven to be a powerful framework for the environmental analysis and the environmental management, thanks to the life cycle approach, which prevents the shift of environmental burdens between life cycle phases, and the comprehensive analysis of all relevant environmental impacts, which shows possible trade-offs.

LCA is useful for the major agro-environmental strategic issues: promotion of a more environment-friendly agriculture, environmental product declaration of food, and environmental design of land use strategies.

The main challenges are to represent the variability of the production systems and sites as well as to adequately reflect the environmental mechanisms. If these challenges are properly addressed, LCA is a powerful tool for decision-support in the agri-food sector.

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