Life Cycle Sustainability Assessment of Dairy Farming at the Grignon Farm

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ABSTRACT

A Life Cycle Sustainability Assessment of dairy production system at the Grignon farm is presented. Two systems are studied, corresponding to the feed mix used before 2008, and the feed mix used thereafter, including a higher share of corn silage, alfalfa, locally produced rape meal and grazing; the functional unit is 1 kg standard FPCM at the farm gate. An innovative approach to assess impacts on biodiversity and soil quality is included, next to relevant environmental LCA impact categories, including water use and land use, as well as social and economic sustainability indicators. Comparison between previous and current diet shows a reduction in global warming potential and cumulative energy demand, two main objectives of the farm. Benefits and trade-offs with regard to other impact categories are presented and discussed, and recommendations are derived for further optimization.

Keywords: Life Cycle Sustainability Assessment, Dairy, Biodiversity,

1. Introduction

1.1. Overview and Context

The experimental farm of Grignon is a mixed crop-livestock farm. It is located at a distance of 40 km from Paris. The farm hosts 120 Prim'Holstein dairy cows with a 30 liter average daily milk production, in two milking times, which represents ca. 1,100,100 liter production every year on the farm. The agricultural net area of the Grignon farm exceeds 500 ha. This surface is dedicated to pasturelands and fodder and cereal production. The main crops are wheat, fodder barley, beer barley, canola, corn, horse bean, alfalfa, and meadows.

In order to reduce the farm's energy consumption and GHG emissions, there has been a change in the feed for dairy cows around the year 2008, which affected the composition of the feed mix. In the following, the new feed composition used since then will be referred to as 'current diet', whereas the alternative feed composition will be referred to as 'previous diet '.

In line with the objectives of the farm there is a need to investigate the consequences of this change in diet on greenhouse gas emissions and energy consumption but also in other potential impacts on sustainability in a wider context, encompassing environmental, social and economic aspects. Therefore, the farm and BASF have conducted together a Life Cycle Sustainability Assessment (LCSA) based on the AgBalance methodology created by BASF (Schoeneboom et al. 2012)

The present study hence quantifies and compares the sustainability performance (based on Life Cycle Assessment and additional sustainability criteria) of dairy (milk) production at the Grignon farm based on the current and the previous dairy cow feed mix.

A critical review has been carried out by a panel of interested parties, represented by external experts.

1.2. Objectives of the Study

The main objective of the study is to investigate sustainability performance of dairy production system at the Grignon farm by quantifying key environmental, social and economic performance characteristics (indicators). Due to the farm's objectives, the focus is on climate change impact and energy consumption.

Sub goal is to investigate the sustainability impact of the feed composition used at Grignon farm, specifically the effect of a change from the feed composition around the year 2008 (previous diet) to the feed used since then (current diet).

The intended audiences of the study include stakeholders of the farm and other interested parties, including the general public.

2. Methods

2.1. Studied Systems and Functional Unit Definition

The systems chosen for this comparative analysis are the dairy cow production system at the Grignon farm with the typical feed composition in the period since 2009, referred to as ‘current diet’, and the dairy cow production system based on the feed composition before 2008, referred to as ‘previous diet’, respectively.

Table 1. Diet composition of current and previous diet for one dairy cow life in absolute quantities (dry weight)

Feed component	System 1: Current diet Quantities [kg dw / cow life]	System 2: Previous diet Quantities [kg dw / cow life]	Origin
Maize silage	10,214	3,815	Grignon farm
Beet pulp	2,818	4,419	market
Alfalfa silage	1,916	0	Grignon farm
Rape meal from Grignon	4,428	0	Grignon farm
Alfalfa hay	3,252	0	Grignon farm
Grain maize	1,929	4,134	Grignon farm
Hay	2,499	2,593	Grignon farm
Molasses	1,851	2,451	market
Grazed grass	1,855	347	Grignon farm
Rape meal, industrial	1,421	3,186	market
Orange skin	243	307	market
Minerals (CaCO3 + NaCl)	618	1,192	market
Wheat straw	437	1,610	Grignon farm
Dried distillers grain	352	560	market
Humid distillers grain	0	1,470	market
Dehydrated alfalfa	4	1,662	market
Horsebean	0	881	market
other	1,140	2,252	market

Table 1 lists the composition of the feed mix for both systems, giving totals of each feed component aggregated over all growing stages of the cows’ life (veils, heifers, dairy cows). The comparison shows that the dominating component in the current diet is by far maize silage (44%) produced on the farm. On the other hand side, previous diet is composed by 24% of sugar beet pulp (purchased from a supplier) and 20% maize silage. ‘Rape meal industrial’ use was reduced significantly in the current diet and is now just 45% of the previous diet (compare Table 1). Rape meal industrial refers to the residual by-product of rapeseed oil pressing, which is purchased by Grignon from the general market. In the current diet, a new type of rape meal was introduced. This rape meal is obtained from a local oil mill, that uses oilseeds from rape produced at the Grignon farm, and has higher residual oil content than the industrial rape meal. Herein, we will refer to this new type of rape meal as "Rape meal from Grignon". The rape meal from Grignon replaces industrial rape meal in the current diet to a large extent; the remaining fraction of industrial rape meal comes from the ready-mixed feed products which are still used in the current diet. Another difference between the systems is the amount of grazed grass which increased by 300% in the current diet.

Dairy cow systems provide several functions: milk, veil (for fattening), manure, and the products derived from slaughter of the cows. The relevant function of the system considered herein is the provision of milk. Allocation is used to resolve multi-functionality (see below).

The functional unit provides a basis for comparing all life cycle components on a common basis and allows direct comparisons among the product systems in question. The systems are compared based on the functional unit of 1000 kg standard fat and protein corrected milk (FPCM).

A simplified representation of the processes considered in the present study is shown in Figure 1. Although not shown, the calculation considers all activities ‘upstream’ from the extraction of raw materials to manufacturing of basic intermediate products etc. and including transportation. The study considers process up to the farm gate; further activities ‘downstream’ as distribution, consumption and end-of-life of the milk are not taken into account. This is usually referred to as “cradle-to-gate” study.

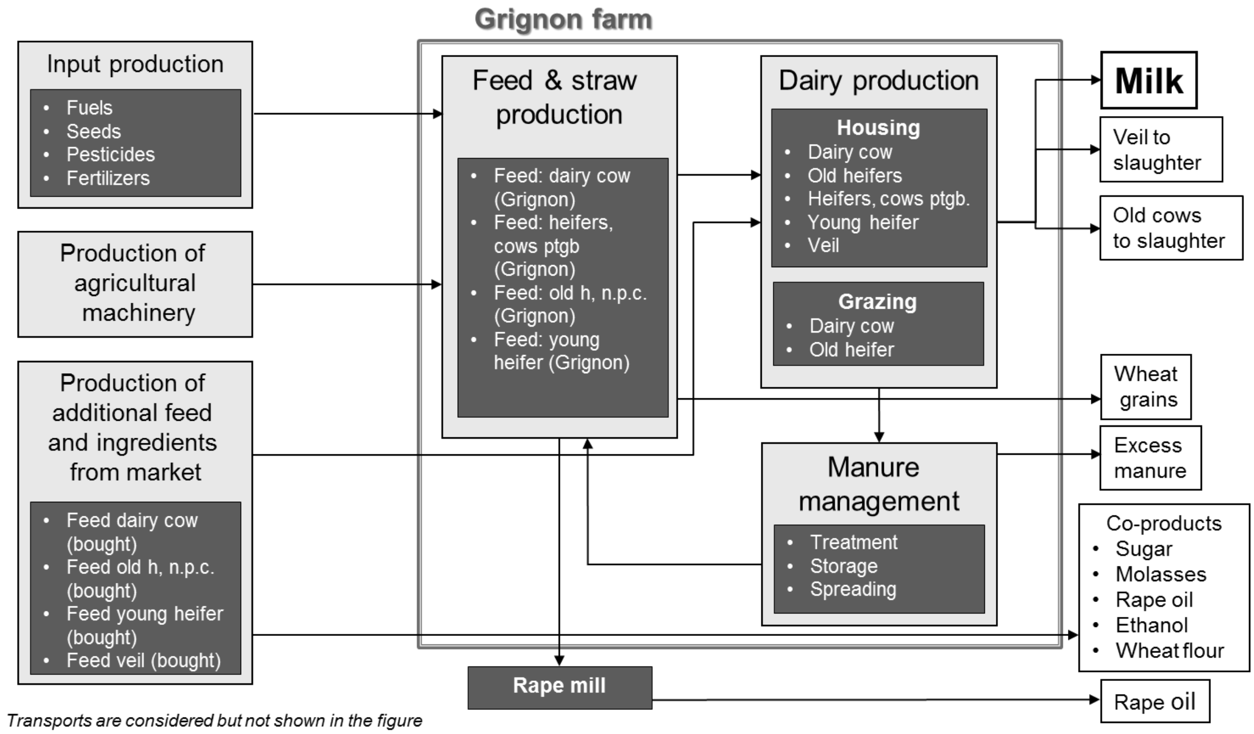


Figure 1. Generic system boundary diagram for current and previous diet.

2.2. Inventory Methods and Assumptions

To achieve the objective of the study attributional life cycle inventory method is used. A consequential LCA was considered to be not necessary for the objectives and intended use of the study, because it is aimed at a retrospective or descriptive comparison of milk production, the system is thus modeled as it was; average or generic data is used. Conclusions of this study do not serve as a basis for long-term policy decision making.

Feed components:

All relevant feed components have been considered, either by collecting data from the Grignon farm, or by consulting relevant databases for appropriate life cycle inventory datasets (see below). Feed components where data was not readily available were neglected when their estimated impact falls below 1% of the total system.

For the feed components which are purchased from an external supplier, life cycle inventory data from the ecoinvent database (version 2.2) was used (ECOINVENT 2007). In a few cases, for example in the case of dehydrated alfalfa and orange skin, an equivalent inventory was not available, and an approximation was taken instead. The datasets for inputs needed to model the production activities at the Grignon farm have all been taken from the ecoinvent database (version 2.2).

Primary data for feed components produced on the Grignon farm, as well as for the dairy cow farming and manure management was collected in a dedicated data collection sheet. The social data for the other processes, i.e., all activities not carried out on the farm, are derived from statistical data for industry sectors (Kölsch et al. 2008). The economic costs are calculated at the production step of the milk, i.e., from the perspective of the farm. Therefore, cost data has only been raised from the Grignon farm; no costs therefore had to be obtained for upstream processes.

The multi-output system ‘dairy cows’ produces milk, excess veil, dairy cows to slaughtering, and excess manure. Both economic allocation as well as the procedure proposed by International Dairy Federation (IDF 2010) for allocation were tested and lead to identical allocation factor for milk of 87%. To ensure consistency between ecoinvent and Grignon specific feed component datasets the same allocation factors are used. For the following multi-output processes economic allocation was applied (allocation factor to co-products derived from ecoinvent documentation in brackets): Feed components: co-products include rape meal (25.7%), beet pulp (3.8%), distillers grain (2.3%) and straw (7.5%).

Excess manure produced by the livestock and not used within the system (for arable production of fodder crops) was treated as substituting an equivalent amount of N, P_2O_5 and K_2O from a mineral fertilizer production process.

Emissions:

CH_4 emissions from enteric fermentation as well as from manure management are calculated based on IPCC 2006, according to the 'tier 3' approach. N_2O, NH_3 and NO emissions from manure management are calculated based on IPCC 2006, according to the 'tier 2' approach.

Emission factors for direct and indirect field emissions of N_2O and CO_2 are taken from IPCC 2006 (tier 1). CO_2 emissions due to land use change (according to IPCC 2006) are not considered because no production area was converted to arable land in the past 20 years.

Water:

The inventory includes consumption of water over the complete product system. Water used in the cow housing system is considered to be 100% consumptive because this water is either diverted to milk, to slurry and manure or consumed otherwise by the animals. The fraction of water applied to agricultural fields with slurry is considered to be transferred to other watersheds and lost through evapotranspiration. In crop production, all forage crops are non-irrigated. Water consumption in industrial manufacturing of fertilizers was modeled based on the following assumptions: 1% of cooling water is considered consumptive (99% returned to the river), based on actual data of the BASF Ludwigshafen production site. As for the water consumption of other water resources we followed the recent study of De Boer et al 2013; these authors included consumptive water use based on ecoinvent: sea water and turbine water (in-stream use) were excluded from the inventory. All other water sources (lake, river, well, unspecified) were assumed to be consumptive. The results were taken from this study and amount to the following numbers: 4 L per L Diesel, 1.3 L per kWh electricity, 4.6 L per ton of concentrate produced at the feed mill, 0.652 L per ton-km road transport, 0.16 L per ton-km for inland ship transport, 0.029 L per ton-km transoceanic ship transport.

In line with the goals of the present study, which are to compare the sustainability of the feed compositions and the contribution of the feed composition to the overall impact, several parameters were assumed to be identical in both product systems: (i) the same milk productivity is assumed for both product systems (10.475 litres per lactation period); (ii) technical itineraries and yields for crop production are assumed to be identical in both systems; (iii) prices for inputs (e.g. fertilizers, pesticides) were held constant for both systems, to average 2012 prices.

2.3. Life Cycle Impact Assessment Method

The environmental assessment is based on established life-cycle impact assessment (LCIA) mid-point indicators as used also in Eco-Efficiency Analysis (Saling et al. 2002) and a wide range of other LCA approaches. Environmental impact categories are: abiotic resource depletion (Saling et al. 2002), climate change (IPCC 2007), acidification (CML), photochemical ozone creation (CML), fresh water eutrophication (Goedkoop et al. 2013), marine eutrophication (Goedkoop et al. 2013), water use related to water scarcity (Pfister et al. 2009), ecotoxicity (Rosenbaum et al. 2008), land use (EDP; Köllner and Scholz 2007, Köllner and Scholz 2008). Primary energy consumption (Saling et al. 2002) was assessed to meet the farm's objective to measure and reduce energy demand.

Additionally, environmental indicators addressing the specific impacts of agricultural activity on biodiversity in agricultural areas, and on soil health and conservation, have been incorporated into the methodology (see Schoeneboom et al, 2012 and references therein). The potential impact on biodiversity is assessed using eight indicators relating to the state of biodiversity, crop management practice (e.g. crop rotation, ecotoxicity potential of crop protection products, nitrogen surplus) and the environmental policy context (e.g. availability of protected areas or agri-environmental schemes). The impact category of soil health is comprised of indicators assessing soil organic matter balance, soil erosion, soil compaction and the nutrient balances of N, P, K.

In terms of economic assessment, both production costs as well as economic performance are taken into account. Production costs are grouped into variable and fixed costs and quantified using an overall total cost of ownership for the defined functional unit (Kicherer et al. 2007). Economic performance is assessed using indicators for farm profitability as the central criterion for economic sustainability, subsidies which may excert distorting economic effects and productivity as measured as the production value of agricultural goods per hectare weighted by the contribution of the agricultural sector to the national GDP.

The social assessment in AgBalance is derived from the SEEBALANCE method for social LCA, which was developed in 2005 by Universities of Karlsruhe and Jena, the Öko-Institut (Institute for Applied Ecology) Freiburg e.V., and BASF (Schmidt et al. 2005, Kölsch et al. 2008). Based on the UNEP-SETAC guidelines for social LCA of products 5 stakeholder categories were defined: Farmer, consumer, local community, internal community and future generations. The SEEBALANCE indicators and data sources are employed to assess the social impacts of industrial up- and downstream processes. For the agricultural activities in the life cycle, a set of adapted social impact indicators was integrated into the AgBalance method which was designed to match closely the same social sustainability topics addressed in the assessment of the upstream and downstream processes.

3. Results

3.1. Environmental Impact Assessment

The contribution analysis of the environmental impacts below makes use of the following category definitions:

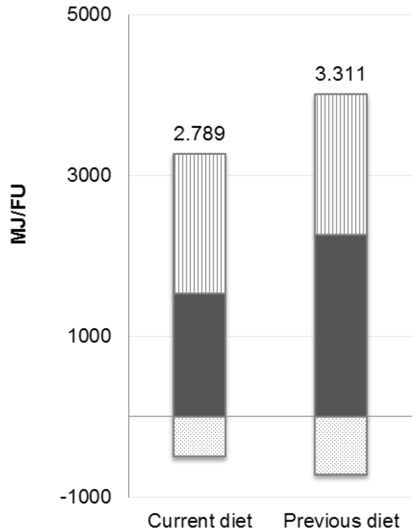
- (i) emissions from manure management
- (ii) emissions from livestock enteric fermentation
- (iii) ancillary input for cow housing: contains among others diesel (production and combustion) needed for supplying and distributing the feed to the cattle on the farm (e.g. extraction of silages from the silo and on farm transports). Furthermore electricity for lighting, pumping of slurry etc. is included. Other materials combined in this category are: consumed blue water, wheat straw for bedding and farm infrastructure (milking parlour and housing system)
- (iv) feed production: aggregated impacts due to production of agricultural inputs and field emissions from fodder crop production
- (v) avoided fertilizer production: Excess manure produced by dairy cows and not used within the system (for arable production of fodder crops) was treated as substituting an equivalent amount of N, P_2O_5 and K_2O from mineral fertilizer production processes. This contribution appears as a negative impact in the graphs.

Because the objectives of the farm are to reduce energy consumption and greenhouse gas emissions, we focus on these two impact indicators first.

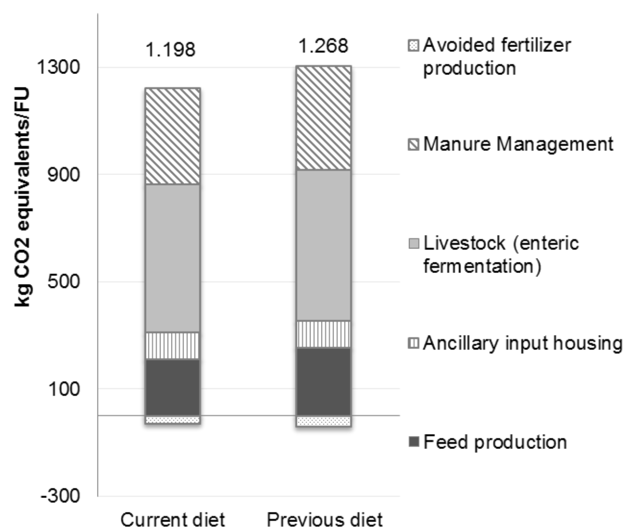
Figure 2 shows the primary energy consumption (excluding biomass feedstock energy for feed) for the current and previous diet calculated excluding biomass feedstock energy in feed. Primary energy consumption of the milk production for 1000 kg FPCM with the current feed mix is 2.8 GJ and 16% reduced in relation to the previous diet. The dominating contributions arise from the diesel and electricity use in housing and the feed production. This in turn is dominated by fuel and mineral fertilizer production and use.

It is noted that the current diet is associated with a higher input of biomass total matter (cf. Table 1), mainly of maize silage from the Grignon farm. If the biomass feedstock energy of the fodder is taken into account (which stems from sun energy), the current diet system exhibits a significantly higher energy consumption of 14 GJ/FU.

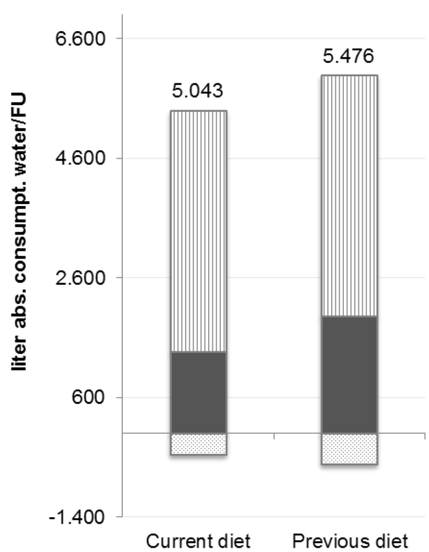
The global warming potential for both systems is shown on the right side of Figure 2. The current diet exhibits a 5.8% lower global warming potential (GWP) compared to the previous diet. The largest contribution to this improvement in GWP of the new diet (i.e., the difference between both systems) comes from the feed production: there is a significantly lower GWP associated with the feed in system 'current diet' than in system 'previous diet' (current: 214 kg CO_2e/FU, previous: 257 kg CO_2e/FU, 17% reduction). In more detail, this difference from feed production can be attributed particularly to the dairy cow feed. In sum, the GWP attributed to dairy cow feed is reduced from 223 kg CO_2e/FU in system 'previous diet' to 175 kg CO_2e/FU in system 'current diet'. This net reduction in GWP is because of the comparably low GWP impact of the production of the new feed components, particularly those produced on the Grignon farm. An inspection of the corresponding input data of these inventories (not shown here) reveals that in oilseed rape, maize, and hay production at Grignon, mixed organic and mineral fertilization is applied, thus reducing mineral fertilizer use. Furthermore, alfalfa, a leguminous (N-fixing) crop, is grown without any addition of mineral N-fertilizer.



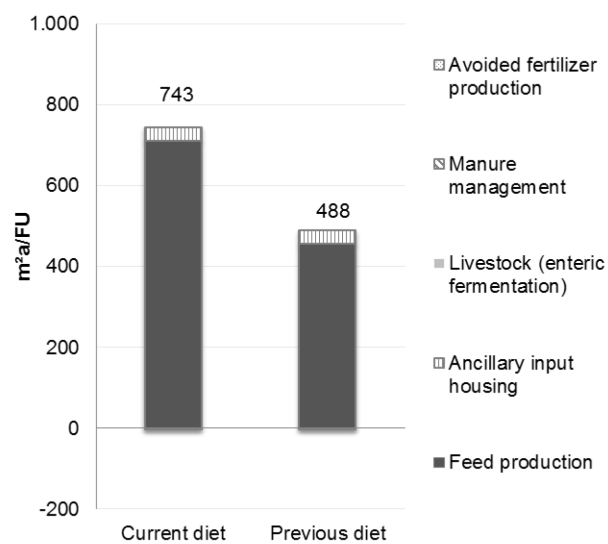
Primary energy consumption excluding biomass feedstock energy of feed



Climate Change impact



Water use impact related to water scarcity



Land use impact (EDP)

Figure 2. Primary energy consumption excluding biomass feedstock energy of feed (left) and climate change impact (right) of the current and previous diet.

The second largest contribution to the reduction in GWP with the current feed is due to changes in methane emissions from manure management. With the ‘current diet’, older heifers and dairy cows are fed in a mixed housing (liquid/slurry and solid manure storage) and grazing (pasture) system, whereas the ‘previous diet’ system used exclusively housing (liquid/slurry and solid manure storage). The decisive factor in the present IPCC modeling approach is the ‘methane conversion factor’ for each manure management system (MCF). This factor is more favorable for pasture, than for solid manure storage, and much more favorable than liquid/slurry storage. In simpler words, the higher the share of pasture in the feed system is, the lower the methane emissions from manure management are.

Analyzing the contribution of each aspect to the total GWP of each system, it is apparent from Figure 2 that livestock emissions of methane from enteric fermentation represent the highest share, followed by methane emissions from manure management. Feed production then itself makes the third largest contribution to the total GWP

Water Use: The impact of water consumption related to freshwater deprivation (water scarcity) is assessed over the cradle-to-gate life cycle of the milk. Forage crop production in the present study does not make use of irrigation; therefore the main contribution comes from the water consumed directly as drinking and cleaning water for the animals. The category 'ancillary input housing' moreover also includes impacts due to use of Diesel fuel and electricity. The impacts of the feed are mostly due to the use of mineral fertilizers. The total volumetric amount of consumptive water per kg of FPCM is 5.0 to 5.5 L in our study; the result of the impact assessment is 1.5 to 1.6 L-eq. per kg FPCM. The amount of water used for drinking / cleaning is 4.0 L in the present system.

The rank order of the two systems appears robust as the "previous diet" product system (with the higher impact) might actually include irrigation in crop production of some feed ingredients purchased from suppliers.

Land Use: System 'current diet' has a 34% higher land use impact compared to system 'previous diet'. Main contributions are due to the use of arable land for feed production at the Grignon farm for the dairy cows as well as the older heifers and non-productive cows (maize -silage and grains-, alfalfa, pasture and oilseed rape). By contrast, sugar beet pulp, which makes up a larger fraction in the previous diet, has a comparably low profile in terms of land occupation. The rather low land occupation of beet pulp is due to being a co-product of sugar production of sugar beet. We applied an allocation factor of 3.8% for beet pulp (91.7% are allocated to sugar and 4.5% to molasses).

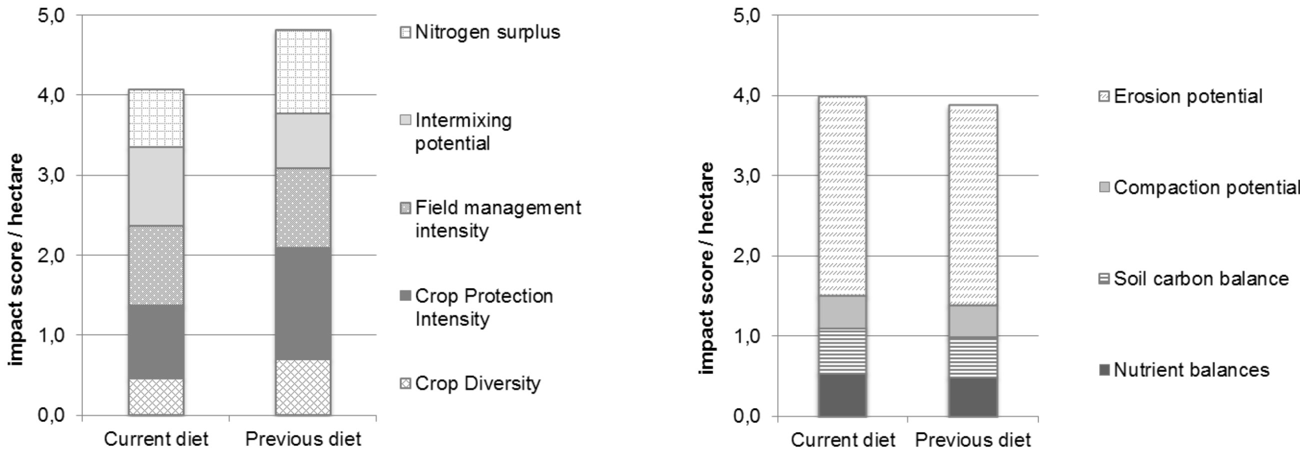
We also assessed other environmental impacts. The results for abiotic resource depletion and marine eutrophication likewise show an improvement for the current diet system relative to the previous diet system. Some other impact indicators show insignificant differences for the two systems, e.g. eco-toxicity potential, acidification potential and photochemical ozone creation potential. The fresh water eutrophication potential shows a worse performance of the current diet system. However, this result is strongly influenced by the contribution from avoided phosphate mineral fertilizer production.

3.2. Farm specific Biodiversity and Soil Assessment

Evaluation of biodiversity and soil indicators was carried out specifically for the agricultural area at the Grignon farm dedicated to the forage crop production (corn, alfalfa, oilseed rape, grassland and pasture, wheat). Wheat is included because wheat straw serves as an input for the cow bed and also as a minor feed component. Other areas, which are not associated with the fodder crops, were not considered.

Biodiversity (figure 3): Except for the indicator intermixing potential, system 'current diet' performs equal or better concerning all indicators. The previous diet performs better concerning the intermixing potential due to the inclusion of oilseed rape as a forage crop. Oilseed rape has a higher intermixing potential with the natural vegetation compared to the other crops. The indicators performing better for the current diet are the nitrogen surplus, the field management intensity, crop protection intensity and crop diversity. The indicator conservation area is determined by location and remains unchanged between both systems (not shown). Agri-environmental schemes were not implemented on the farm.

The evaluation of management indicators related to soil showed only minor differences between both systems.



Biodiversity Soil quality and conservation

Figure 3. Weighted impacts on biodiversity in agricultural areas (left) and soil quality and conservation (right) of the current and previous diet on agricultural areas for forage crop production at the Grignon farm.

3.3. Socio-Economic Impact Assessment

In this comparative assessment, the basic socio-economic figures of the farm remained were assumed to remain unchanged, to focus the comparison on the effects of the change in feed composition. The resulting impacts – both positive and negative indicators – attributed to system ‘current diet’ are generally higher at the Grignon farm, and lower for the farm-external activities. This is related to the higher amount of feedstuff produced on farm in system ‘current diet’ compared to system ‘previous diet’, where more feed was bought from the market. Hence Grignon farmers/farm employees, and local community potentially benefit from the new feed system in so far as potentially more labor activities are carried out on the farm itself, meaning that e.g., more wages, employment opportunities, and social security provisions are attributed to the milk production. On the other hand, the need for more land to produce the feed poses additional needs for productive area, with consequences for the land market and potential future restrictions in access to land.

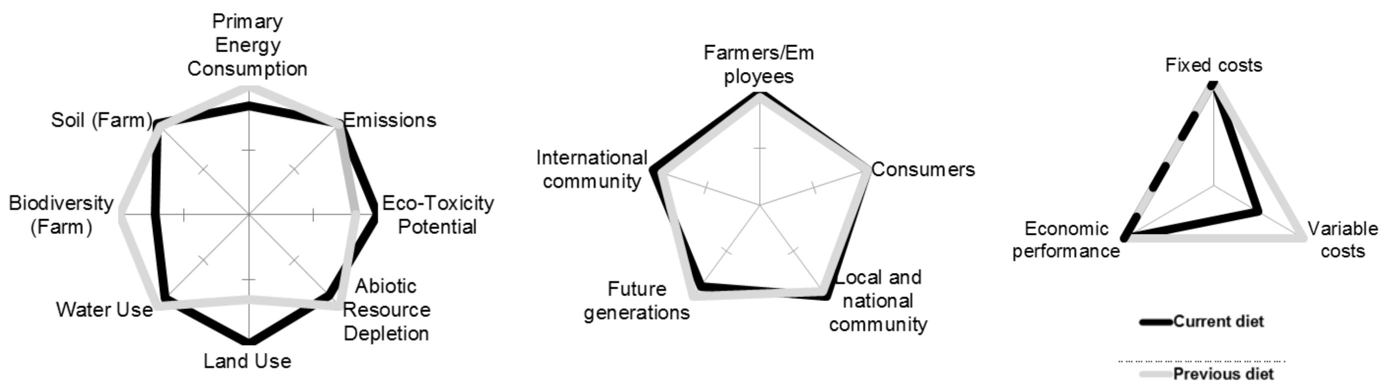
The economic assessment showed that the new feed (current diet) can potentially contribute to cost reductions for the farm. Direct costs to produce the higher amount of feed on the farm in the current diet are lower than the purchasing costs for the substituted components of the previous diet. The overall costs for use of fixed assets and total farm profits are unchanged in the two systems.

3.4. Sensitivity Analysis

Sensitivity analyses on multiple relevant methodological choices (allocation factors, milk productivity, emission factors) showed that allocation factors chosen for by-products (e.g. sugar beet pulp, distillers grain or rape meal), milk-meat allocation factor, milk productivity as well as the methane conversion factor for the manure management system have a significant influence on the absolute indicator results. The absolute deviations in GWP amounted to 20%, the standard deviation is 10%. The relative ranking of the alternative systems is however hardly affected, therefore, the conclusions drawn above remain valid.

3.4. Aggregated Results and Trade-off Analysis

Normalized and aggregated results are shown in Figure 4 to give a concise representation of the individual indicator results discussed in the preceding sections.



Environmental fingerprint Social fingerprint Economic fingerprint

Figure 4. Relative results obtained by internal normalization to the highest impact. Smaller figures indicate better performance. Dark line: system ‘current diet’; grey line: system ‘previous diet’. Social indicators for the stakeholder group ‘Consumers’ have not been evaluated in the present study.

The environmental fingerprint shows advantages of the new feed composition in the current diet related to a lower cumulative energy demand, abiotic resource depletion and the biodiversity potential of the agricultural area at the farm. The global warming potential is considered as part of the aggregated category emissions, and is lower for the current diet. The category emissions further contains the impact categories: acidification potential (AP), photochemical ozone creation potential (POCP), ozone depletion potential (ODP), and impact on water quality. The previous diet (old feed mix) has advantages related to a lower land use. The difference in eco-toxicity potential falls within the uncertainty of the USEtox impact assessment methodology. The higher impacts from land use in the current diet primarily are due to a higher land occupation on the farm itself. As shown in Figure 3, the biodiversity indicators related to on site management of the production area at the Grignon farm indicate an improvement (indicator ‘Specific Impacts on Biodiversity in Agricultural Areas’) with the current diet, and therefore the higher land use is balanced by a higher biodiversity potential on the farm area.

The social fingerprint shows that at the level of stakeholder categories, the impacts aggregated over the life-cycle lead to negligible differences between the two alternative systems.

4. Conclusions and Recommendations

The main objective of the farm is to reduce the climate change impacts and energy consumption of its produce. The present results clearly show that this objective was met with the introduction of the new cattle feed (current diet). Dairy cow feed crops produced at the Grignon farm contribute to lower GWP impacts of the current diet. However, the absolute GWP impacts foremost are due to emissions from livestock, which contribute with more than two-thirds to overall emissions. This underlines the relevance of investigating mitigation options of GWP impacts from livestock emissions. Mitigation strategies for CH_4 from enteric fermentation could be based on optimizing the feed mix for higher digestibility and usage of fat sources with reduction potential concerning methanogen bacteria. Regarding the manure management system, storage time and storing conditions (e.g. type of cover, temperature) are important parameters for reducing methane emissions. Furthermore, biogas plants provide excellent options for reduction of these emissions. Gastight covered biogas plants usually emit about 1 % of the CH_4 forming potential. In contrast to this, the liquid manure management system considered in this study leads to emissions in the dimension of 20% of the CH_4 forming potential. Additionally the energy produced by the biogas plant can substitute fossil fuels.

Few trade-offs between environmental consequences of introducing the new feed composition exist. The higher land use associated with the current diet is – at least to same extent – balanced by a higher biodiversity potential on the farm area. This may be further supported on the farm through targeted implementation of agri-environmental schemes, for example, flowering strips. The higher land use in system 'current diet' could also lead to a higher risk for indirect land use change. This has not been considered in the present study due to high uncertainty associated with such evaluations. Nevertheless this could be assessed in a further step for a better understanding of global environmental consequences of the two systems.

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