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Combining environmentally and economically sustainable dairy and beef production in Sweden

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ABSTRACT

To achieve a more sustainable food sector, a supply chain approach is needed. In this study, experts in different areas along supply chains co-operated in an interactive process to define future environmentally sustainable supply chains of milk and beef. The basis was to use existing techniques, to have production performance corresponding to the best quartile of today and to consider other sustainability aspects, such as economics. The work resulted in concrete descriptions of alternative product chains for delivered milk and beef. To also permit concrete descriptions of the latter part of the product chains, two consumer-packed end products were selected for monitoring, namely fresh milk and sirloin steak. The production systems investigated comprised cropping, livestock production, industrial processing and production, logistics, packaging and wastage and distribution, but not retailers or consumers. The study area was a Swedish county and the reference level was its production of milk and beef in 2012. The future product chains were assumed to deliver the same amounts of commodities as in 2012, but with reduced environmental impact. Primary production was required to be at least as profitable as today. Beside description of the current situation, three alternative scenarios were created, focusing on delivery of ecosystem services, plant nutrient circulation and minimising climate impact, respectively. Life cycle assessments were performed for these four scenarios (reference plus three alternative scenarios) for single-product chains and county-wide. Furthermore, production costs in primary production were calculated for the four scenarios. The results revealed great potential to reduce the negative environmental impact of Swedish dairy and beef production at current volumes, irrespective of whether ecosystem services, plant nutrient circulation or climate impact is in focus. The single most important factor for decreased environmental impact for livestock production was increased production efficiency. Measures in agriculture, especially concerning feeds, were critical, but actions in processing and distribution also contributed. All alternative scenarios resulted in lower production costs than at present. It was obvious that as dairy and beef systems are connected, the potential for their environmental improvement must be analysed together. In conclusion, increased efficiency can decrease the negative environmental impact of Swedish cattle production and also reduce costs to the farmer.

1. Introduction

In order to design more ecologically sustainable food production, it is necessary to study the entire supply chain, starting from the primary production and its inputs and ending when the commodity reaches the consumer. It is also necessary to consider the economic sustainability of primary production in such a chain, as profitability is a precondition for the food chain to be relevant and sustainable. The need to study the whole chain is obvious to the life cycle assessment (LCA) community and is being embraced by a growing fraction in society (Seuring and Müller, 2008). Most studies aiming to propose and analyse food production systems with better sustainability performance use a simplified approach to identify the potential for improvement in different steps of the life cycle without stating how the improvement will come about, just how large it is. These assumptions are often based on general assumptions on the potential in each separate step. This is a useful approach for identifying and quantifying the potential, but is less valuable for providing practical information on relevant actions to be taken by food chain actors such as farmers, industry, retailers, consumers and various public decision makers.

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For a proposed system to be implemented, overall economic viability in primary production is essential. Neglecting this in studies will seriously hamper the interest among stakeholders and delay or prevent necessary improvements in environmental performance. An immense number of LCA studies have been conducted on food production, including cattle production in the Nordic region (e.g. Flysjö et al., 2011; Roer et al., 2013; Mogensen et al., 2015). However, these LCAs have not been accompanied by simultaneous estimates of economic sustainability.

The empirical data presented in this paper were obtained in the '*Paths to a Sustainable Food Sector*' project, which adopted an interdisciplinary approach embracing several production chains (milk, beef, pork, chicken and bread) and covering animal production, feed production, industrial processing, packaging and distribution (Sonesson et al., 2015). The aim of the project was to present alternatives for specific food supply chains with better sustainability performance and also realistic and concrete enough for food chain stakeholders to use in their decision making. The focus was on improved production in a short-term perspective, whereas changes in consumption patterns were beyond the scope of the project, so that production levels of each commodity remained unchanged in the future scenarios. The parts of the project dealing with dairy and beef production and their interrelationships are presented in this paper.

This paper provides detailed descriptions of the current supply chains for milk and beef in the county of Västra Götaland in Sweden, focusing in particular on the supply chains for fresh milk and sirloin steak. Furthermore, future scenarios for these supply chains are described in which the amount of commodity produced remains the same as at present, but the environmental performance is improved. Based on these assumptions, the objectives of the paper are to:

- Quantify the environmental impact of these supply chains and compare it with that of the current situation as a reference using LCA
- Quantify the costs in primary production of dairy and beef for the reference case and for the scenarios, based on current cost levels and expected economic-political conditions.

2. Materials and methods

2.1. Working process

The project was set up in collaboration with experts on production along the supply chains of milk and beef, such as agronomists, animal scientists, economists, food engineers and packaging and supply chain management experts. The general working process was interactive (Fig. 1).

Table 1
Names and descriptions of the three goals targeted in the Ecosystem, Nutrients and Climate alternative production scenarios, compared with the typical current system (Reference).

Name	Goal of scenario	Impact categories to be addressed in the alternative scenarios
Ecosystem scenario	Reduced local impact on ecosystems. Maintain and develop ecosystems	Eutrophication Biodiversity Eco-toxicological impact Land use
Nutrients scenario	Optimise plant nutrient use and supply	Eutrophication Acidification Use of minerals (phosphorus) Land use
Climate scenario	Reduce climate impact	Climate change Use of fossil fuels Land use (less land use, making space e.g. for bioenergy production)

2.2. Scope

2.2.1. Development of alternative production scenarios

To avoid possible trade-offs between environmental impacts within the production systems developed, three alternative production scenarios were designed in order to improve the performance of three clusters of environmental objectives. These three clusters were: 1) focusing on local ecosystems (the Ecosystem scenario), 2) efficient use of plant nutrients (the Nutrients scenario) and 3) reduced climate impact (the Climate scenario). These clusters were chosen because they have been identified as the three major global environmental challenges (Rockström et al., 2009). They also correspond to clusters of Swedish national environmental objectives (Swedish Environmental Objectives Council, 2008). In Table 1, the connections between each cluster and environmental impact category are listed. The expert group first designed reference production systems reflecting the current systems for dairy and beef production. A 'Reference' scenario describing the typical production at present was based on detailed descriptions of the current Swedish cattle production system and possibilities to improve it. Three improved systems for the supply chains, each meeting the clusters of environmental impacts described above, were then developed by the experts. This was done by using literature and their own knowledge, combined with expertise on the environmental impact of food supply chains. The close cooperation between different experts ensured overall improved supply chains in the so-called alternative production scenarios.

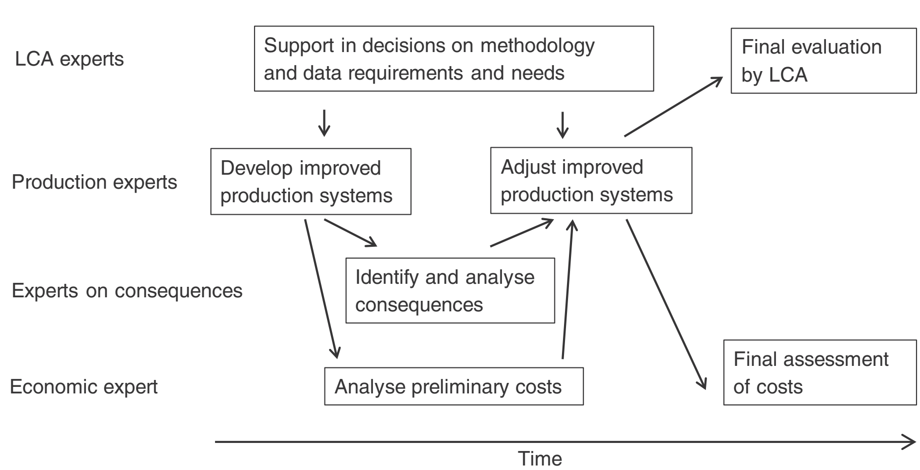

Fig. 1. Schematic diagram of the working process in the '*Paths to a Sustainable Food Sector*' project.

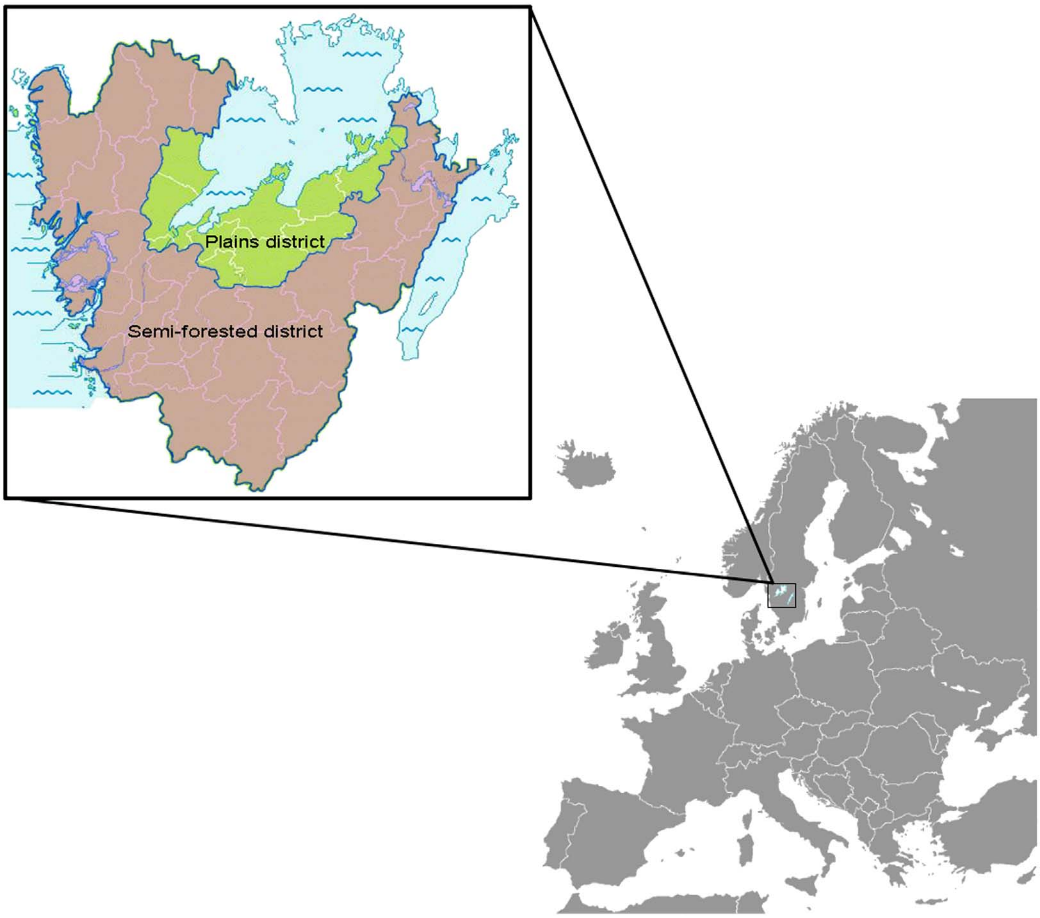

Fig. 2. Map of the Swedish county of Västra Götaland in north-western Europe, showing the plains and semi-forested districts.

2.2.2. System boundaries

The geographical study area was limited to the county of Västra Götaland in south-western Sweden, in the European part of the northern temperate climate zone (Fig. 2). Västra Götaland is the most cattle-dense region of Sweden and embraces many typical physical characteristics of nature in the country. Ten of the 49 municipalities in the county were categorised here as falling within the plains district (mainly clay soils) and 39 into the semi-forested district (mainly lighter-textured soils) (Fig. 2). The area of semi-natural pastures in the county is 60,000 ha. The cattle herd structure is similar to the average in Sweden (Table S1).

2.2.3. Functional units

In the study two different functional units were used. The first was the total production of milk and beef in the region, after primary processing, including all upstream processes. For dairy this means after initial milk treatment and for bovine carcasses after slaughter. The second functional unit was one litre medium-fat fresh milk (1.5% fat) or one kg bone-free sirloin steak (central cut up, consumer packaged), at retail intake. The data for primary production were the same as for the first functional unit and remaining supply chain data were added. The reason for limiting the study of later stages of the supply chain to just two single products was the huge diversity of products in later stages. This approach means that LCA results are presented here for the entire primary production in the county of Västra Götaland, but only case study results for the chain beyond primary processing.

2.2.4. Allocation

Two slightly different approaches to allocation were applied. The first was connected to the region-wide functional units (all milk and beef produced). This was mainly connected to by-product and central manure management, where biogas was produced and the residual slurry was used as fertiliser. Incineration of some by-products delivered heat and in some scenarios phosphorus in ash was used as fertiliser. These products were assumed to replace other means of producing the same functions (energy, nutrients) and the emissions avoided by this were reported as negative emissions from the system. For allocation within crop rotations, the emissions and resource use that occurred were charged to the actual crop, except for measures benefiting all crops, such as phosphorus application and green manuring, which were distributed to all crops on an areal basis. Emissions from manure in animal housing and storage were included in the animal system, whereas emissions from manure transport and spreading were allocated to crop production. The allocation factors for milk and meat (culled cows and calves destined for meat production) from dairy production were based on prices received by farmers. The allocation factors were very similar between scenarios, 87–88% to milk and 12–13% to meat (Table S23). For the second set of functional units, economic allocation was used in the dairy supply chain. In the beef supply chain, mass allocation was applied to the carcass, while in the remaining supply chain economic allocation was applied. The choice of economic allocation was motivated by the need to have a common approach throughout all supply chains studied, since in addition to beef and dairy, chicken, pork and wheat bread were also analysed in the project.

2.3. Life cycle inventory

The Reference scenario created reflected current (2012) cattle production in the county of Västra Götaland. In that year, the production volume was 494,700 t of energy-corrected milk (ECM) and 20,977 t of bovine carcasses, veal excluded (Swedish Dairy Association, 2012; Statistics Sweden, 2014; Taurus, 2013). These volumes were also aimed for in the alternative scenarios. In creating the improved production systems in the alternative scenarios, our own knowledge and that of experts in the field was used to quantify production performance representing the upper quartile of farms for the parameter in question. The acreage of managed semi-natural pastures was an evaluation parameter in the Nutrients and Climate scenarios, but maximised area was a goal in the Ecosystem scenario, as these pastures contain a vast biodiversity, as a proxy for ecosystem services. The reference state for Swedish government policy on biodiversity is a pre-human landscape where large, now extinct herbivores kept the landscape partly open (Vera, 2000; Swedish Species Information Centre, 2015).

Dairy and beef production are connected to each other. The alternative scenario calculations of number of cattle needed were based on dairy production to first obtain the current amount of milk. Beef from the dairy cows and their offspring was then complemented with beef from suckler herds to match the beef amount in the Reference scenario.

Several possible alternatives for improved cattle production systems were then created. The cattle were situated on model farms with dairy production and beef production with suckler herd operations or finishing cattle with steers and heifers or bulls, depending on alternative scenario (Table S2). An overview of animal flows is shown in Fig. S1. In all alternative scenarios, survival rate of calves and cows was generally increased, as was longevity in dairy cows (Tables S3–4). Furthermore, all alternative diets were free of soybean products and products based on oil palm, fat and other by-products, and totally replaced with local protein feeds.

In dairy production, there were both moderate-yielding (9000 kg ECM per cow and year) Scandinavian Red cows with initially eight alternative feed rations and high-yielding (11,000 kg ECM) Holstein cows with initially three alternative feed rations (Spörndly, 2003; Liljeholm et al., 2009). Selected feeds and feed rations are shown in Tables S5–8. Assumptions for the moderate milk yield system were lower mortality for cows and calves, lower calving age and lower replacement rate than for the high-yielding cows. The moderate-yielding cows were grazed for at least three months annually, whereas grazing in the high-yielding alternative was for exercise only. Typical feed for the high-yielding alternative was highly fertilised grass silage, partly in combination with maize silage.

In all alternative scenarios, dairy cows were inseminated with sex-sorted semen for replacement or beef breed semen for improved calves to beef production. For both dairy × beef cross-breed calves and beef cross-breed calves from suckler production, several feed ration alternatives were created (NorFor Nordic Feed Evaluation System, 2008–2012). There were extensive systems based on semi-natural pastures and forage, as well as intensive systems based on forage or maize silage. Selected feeds, feed rations and production models are shown in Tables S5–6; 9–11. In summer, all suckler cows were kept on semi-natural pastures, but in winter grass silage, partly including reed canary grass, was fed. In the Reference and all alternative scenarios, a constant number of calves was omitted from the calculations for beef production, as they were assumed to be used for veal.

Cattle housing varied between systems and scenarios. Manure was handled as slurry in the dairy and beef finishing operations, but as solid manure for the suckler cows (Table S12). Emissions of ammonium, nitrous oxide and methane emissions in manure handling were lowered in the alternative scenarios and calculated according to IPCC (2006), Lindgaard Jensen (2011) and Swedish Board of Agriculture (2013). Improvements in manure management focused on better utilisation of plant nutrients and reduced emissions of ammonia from storage and spreading. In all scenarios, lagoons were covered. In the Ecosystem scenario, manure was incorporated into soil within 1 h, while in the Nutrients and Climate scenarios spreading was done with a trailing hose spreader and manure was also acidified to reduce NH_3 emissions at spreading (Table S13). Doses were adjusted to match plant requirements, rather than following directives on maximum phosphorus application. In general, manure was applied in crop rotations where the nutrient utilisation was best, which meant that manure was sometimes used on other farms instead of the farm of origin.

Roughage was produced on the cattle farms, but grain and protein feeds could be produced on other farms included in the study, such as arable or pig farms (Tables S14–22). The main crop production measures concerned crop rotations and the use of manure and other plant nutrient sources. Reduced pesticide use was important in the Ecosystem scenario. In general, more varied crop rotations, with leys and other non-cereal crops, reduced the need for pesticides and mineral fertilisers. Mechanical weeding replaced herbicides to a large extent. As a consequence, the use of catch crops to reduce nitrogen (N) losses was somewhat limited in the Ecosystem scenario compared with the other scenarios. In the Nutrients and Climate scenarios, similar crop rotations, farm management and plant protection measures were used and precision fertilisation was applied, hence improving nutrient use efficiency. The similarity between these scenarios was because efficient nutrient management coincided with reduced climate impact. The most important difference between the two scenarios was that reduced tillage was introduced in the Climate scenario, and this required somewhat increased application of herbicides. A more efficient chain of machines for cutting and harvesting of ley was also introduced in the Climate scenario. A common and important improvement for all three alternative scenarios was that yields increased mainly due to better crop rotations, better management and an expected effect from the use of new cultivars.

The post-farm part of the supply chain was divided into four parts: processing, distribution, packaging and by-product management. Some measures needed to be coordinated to avoid sub-optimisation. In the post-farm supply chain, few improvement measures involved conflicts between goal scenarios. Therefore only one alternative scenario was developed and used for all three alternative scenarios (Table S24).

From the initial LCA, one improved production system was selected for each alternative scenario. Detailed LCA and cost calculations were performed for Reference and for these three selected systems:

- Ecosystem scenario: high-yielding dairy production + complementary beef production on semi-natural pastures
- Nutrients scenario: high-yielding dairy production + complementary indoor intensive beef production
- Climate scenario: moderate-yielding dairy production + complementary indoor intensive beef production.

2.4. Life cycle impact assessment

LCAs based on the inventories were conducted both for the separate product chains of fresh milk and sirloin steak and for the whole county of Västra Götaland. These LCA calculations were performed in SimaPro (PRé Consultants, 2007), which contains a database, Ecoinvent 3.0 (2013), that was used for background data not determined within the project, such as energy production and packaging materials. The following environmental impact categories were considered using impact assessment methods suggested in the ILCD Handbook (European Commission, 2011): global warming potential; terrestrial, freshwater and marine eutrophication; and acidification. The applied weighting factors are presented in Table S25. Cumulative energy demand was quantified according to Frischknecht and Jungbluth (2003), where the method includes all upstream energy use as well as energy used for energy extraction, refining and transport. The use of fossil phosphorus (P) was estimated by quantifying the inflow of phosphorus in feed and fertiliser, as no other inflows were relevant. Finally, for pesticides a simple method that quantifies the number of recommended doses of all pesticides was used as an indicator of pesticide dependency in the cropping system. The choice of impact categories was based on experiences from a large number of previous LCA studies of dairy and beef.

Allocation was based mainly on the economic value of the products.

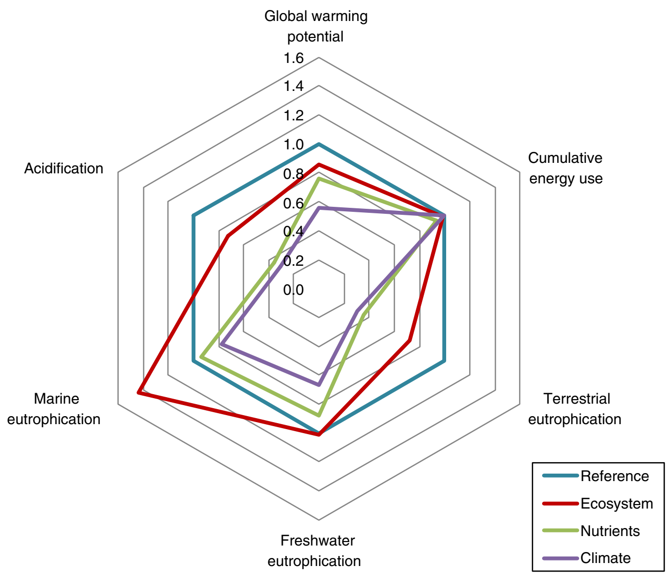

Fig. 3. Relative change in environmental impact for medium-fat fresh milk (1.5% fat), comparing the three alternative scenarios Ecosystem, Nutrients and Climate with the current situation (Reference = 1). A value < 1 indicates lower impact.

A sensitivity analysis for three uncertain parameters was undertaken in order to investigate the robustness of the estimated environmental impact and the interpretations of the results. Time perspective on global warming potential was chosen as a parameter to catch the robustness of the methodology, where 100 years as baseline was compared to 20 and 500 years as described in IPCC (2007). Ammonia emissions was chosen to catch the significance of possible technical means on a farm level, where the anticipated efficiency was compared to lower efficiency, 50 and 25% of baseline. Marine eutrophication from feed production was chosen as it is closely related to crop yield, which is the most unpredictable parameter in the study. Hence, anticipated crop yield was compared to 80 and 120% yield of baseline.

2.5. Calculation of production costs

The calculated business economic costs of primary production included both short-term variable costs and long-term costs such as depreciation and interest on new buildings, machinery, drains and fences. The production costs per kg of feed produced on-farm were calculated as Costs in SEK/kg harvested feed = (Σ quantity of means of production × price of means of production − environmental payment and area aids) / produced quantity (1 SEK = 0.11 EUR). The following means of production were included in the cost calculations: land, seeds, N-P-K fertiliser, pesticides, diesel, silage additives, grain drying, labour, interest on working capital, interest, depreciation and maintenance of machinery, and various other means of production of less economic importance. Environmental payment was payment for grazing semi-natural pastures. Areal aids included support for less favoured areas and for semi-natural pastures. They also included the single farm payment, because grazing is required for obtaining this aid on such pastures. For arable land, the single farm payment was not included because this aid is awarded for arable land irrespective of whether it is cultivated or not.

The production costs per kg of milk and per kg bovine carcass weight were calculated as cost in SEK/kg product = (Σ quantity of means of production × price of means of production − animal premium) / quantity produced. The following means of production were included: farm-produced feed, purchased feeds, purchased live animals, bedding material, energy, labour, interest on animal and working capital, depreciation, interest and maintenance of buildings, and various other means of production of less economic importance. It was assumed that all roughages, feed grains and protein feeds used in cattle production were grown on the farm where the animals were kept or on a neighbouring farm, so transport and transaction costs for these feeds were non-existent or negligible. Animal premium is a subsidy for cattle older than one year.

The prices of most means of production were mainly taken from Area calculations and Databook of the Swedish University of Agricultural Sciences (2014), complemented by costs for labour from Nelson (2002) and for buildings from Johnsson et al. (2004), with prices updated to the current price level and other expert opinions. Data for 2015 on animal premium, support for less favoured areas, single farm payment and environmental payment to semi-natural pastures with common and high nature values were obtained from the Swedish Board of Agriculture (2015; Table S26).

3. Results

3.1. LCA of the scenarios

3.1.1. Evaluation of product chains

The LCA calculations showed that in the product chains for both fresh milk and sirloin steak, feed production caused the greatest environmental impact except for global warming potential, for which the animals, including their feed conversion, were the main contributor (Tables S27–28).

Medium-fat fresh milk performed better in the alternative scenarios than in the Reference except for the impact category marine eutrophication in the Ecosystem scenario (Fig. 3). The profiles for the Nutrients and Climate scenarios looked similar, and the improvement potential was greatest for acidification and terrestrial eutrophication, followed by global warming potential and freshwater eutrophication. Terrestrial eutrophication and acidification are mainly caused by ammonia emissions, which were reduced by a number of measures in the scenarios, such as covered manure lagoons and acidified manure. Other factors that contributed in a general way were improved feed production and higher milk yield (Ecosystem and Nutrients scenarios) and less wastage of milk combined with lower replacement rate of cows (Climate scenario). The change to bioenergy in all three scenarios also contributed, but to a lesser extent. The energy use was not reduced in any scenario. Marine eutrophication increased in the Ecosystem scenario as a result of using a large share of domestically produced protein feed, which caused more nitrate leaching than imported or by-product based feeds.

For sirloin steak, the magnitude of most environmental impact categories increased in the Ecosystem scenario, but the Nutrients scenario also showed increases for many categories (Fig. 4). This was because in the Ecosystem and Nutrients scenarios, the number of calves coming from the dairy system decreased as a result of higher milk yield per cow and thus fewer cows being required to match the total milk volume in the Reference scenario. To maintain the volumes of beef, more suckler cows are needed. Suckler-based beef production is less environmentally efficient, as the beef produced has to carry the whole burden of the dam, whereas in dairy-based beef production the milk carries a large share of the dam's environmental impacts. What is not shown in Fig. 4 is that the Ecosystem scenario delivered a greater acreage of semi-natural pasture used, which was used as a proxy for contribution to biodiversity (Swedish Species Information Centre, 2015). Moreover, the Ecosystem scenario was built on extensive forage-based beef production, where ley production was beneficial for the environmental impacts of arable farming since it gave better crop rotations than grains only. In the Nutrients and Climate scenarios, most of the beef production was based on intact bulls reared indoors with a relatively high proportion of grain and other concentrates. This increases daily weight gain but causes negative impacts in arable farming, which was not captured in the LCA results.

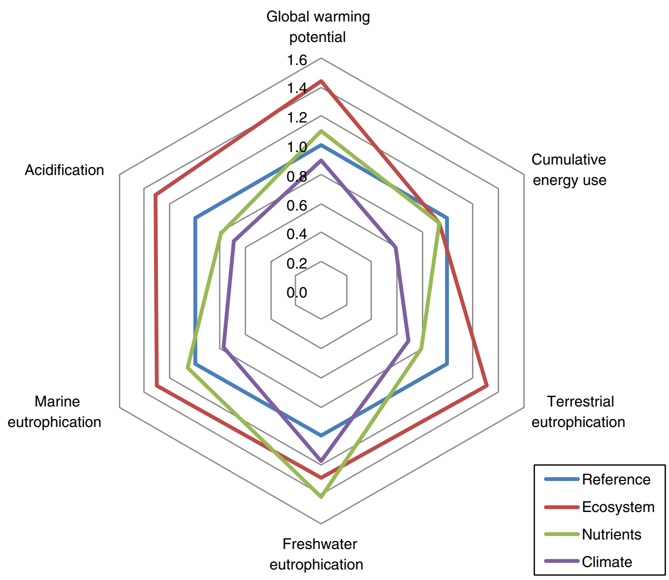

Fig. 4. Relative change in environmental impact for the bovine retail cut sirloin steak, comparing the three alternative scenarios Ecosystem, Nutrients and Climate with the current situation (Reference = 1). A value < 1 indicates lower impact.

3.1.2. Evaluation of the county system

In addition to quantifying environmental impacts of single-product chains (Section 3.1.1), the total emissions from the different agricultural production systems, including farm inputs such as fertilisers and feeds, were evaluated together (Tables 2; S29). By analysing the impacts in this way, the causal connections between dairy and beef can be identified. It should be borne in mind that all scenarios used here delivered the same amount of products and hence they are comparable. Still, beef production in the Ecosystem scenario had higher environmental impact across impact categories. One of the main reasons was that the beef production system was designed to utilise large areas of semi-natural pastures (Fig. 5), which led to higher emissions of methane due to longer rearing periods (steers instead of intact bulls, higher roughage proportion, etc.). The second, and more important, reason was the focus on design of the dairy system, where high-yielding cows were used in the Ecosystem scenario, leading to fewer calves from the dairy system entering the beef system. This in turn led to a need for more suckler cows to maintain beef production at the Reference level, leading to higher impacts for the county system as a whole. However, suckler-based beef production used a larger acreage of semi-natural pastures (Fig. 5). Overall, therefore, improvements in dairy for the impact categories global warming potential and acidification outweighed the increases in beef production, and intense dairy production facilitated more use of semi-natural pastures by suckler cow production. The same tendency was observed for the Nutrients scenario, in which the categories where beef production increased impacts, as a result of the need for more suckler cows, were compensated for by more environmentally intensive dairy production. For the Climate scenario, the number of calves from the dairy system entering the beef system was in the same range as for the Reference scenario due to similar milk yields, and hence this effect was limited. The improvements for both systems were due to internal increases in daily weight gain and feed efficiency, leading to less methane per kg meat, and more feed-efficient breeds of the calves from the dairy cows. Beef production in the Nutrients and Climate scenarios was largely based on indoor rearing of intact bulls, which increased production efficiency but did not contribute much to management of semi-natural pastures (Fig. 5).

3.1.3. Sensitivity analysis of the county system

The results were valid also when modifying the three uncertain parameters (Tables 3, S30–32). The total impact of global warming potential remained the same in the Ecosystem and Nutrients scenarios, when using 20 or 500 years perspective instead of 100 years. However, the methane emittent beef production in the Ecosystem scenario composed a higher proportion in the 20 year perspective but a lower proportion in the 500 year perspective. The Climate scenario resulted in a somewhat higher global warming potential when 20 years perspective was used, but a much lower impact in a 500 years perspective, due to lower emissions from dairy cows. Diminishing the effect of measures to reduce ammonia emissions to 50 or 25% of baseline, still significantly improve environmental impacts in the alternative scenarios compared to the Reference. Marine eutrophication is highly dependent on crop yield, as a 20% lower yield in the Nutrients scenario will result in higher emissions than 100% yield in the Reference scenario (Table 3). However, 80% yield in the Reference would result in even higher emissions (data not shown). Ecosystem consistently has higher emissions than the Nutrients and Climate scenarios.

3.2. Production costs in the scenarios

The estimated total cost per kg of milk was lowest in the Ecosystem and Nutrients scenarios, about 2.85 SEK/kg (Fig. 6; Table S33). In both these scenarios the cows were high-yielding (11,000 kg/year). The costs were substantially higher in the Climate scenario, approximately 3.35 SEK/kg, where the cows were moderate-yielding (9000 kg/year) but highest in Reference, about 3.65 SEK/kg, where milk yield was only 8300 kg. A high yield per cow results in lower costs for buildings, labour and feed per kg of milk compared with lower-yielding systems.

Table 2
Total potential environmental impact from agricultural production, including inputs to agriculture, in Västra Götaland county in the alternative scenarios Ecosystem, Nutrients and Climate compared to present (Reference). Relative values, where 100 = total emissions for the Reference scenario for each category (dairy, beef and total), where measured units have been kept due to readability although proportions usually are expressed without units.

	Global warming potential, ton CO_2-eq.	Acidification, kmol H^+-eq.	Terrestrial eutrophiccation, mol N eq.	Freshwater eutrophiccation, kg P-eq.	Marine eutrophiccation, ton N-eq.	Cumulative energy demand, TJ-eq.
Ecosystem						
Dairy	89	75	65	112	158	103
Beef	115	105	102	123	145	148
Total	100	86	91	116	152	116
Nutrients						
Dairy	78	37	14	93	98	92
Beef	80	64	61	103	98	117
Total	79	47	47	96	98	99
Climate						
Dairy	58	32	8	72	89	67
Beef	69	53	51	90	75	111
Total	63	39	38	78	82	79

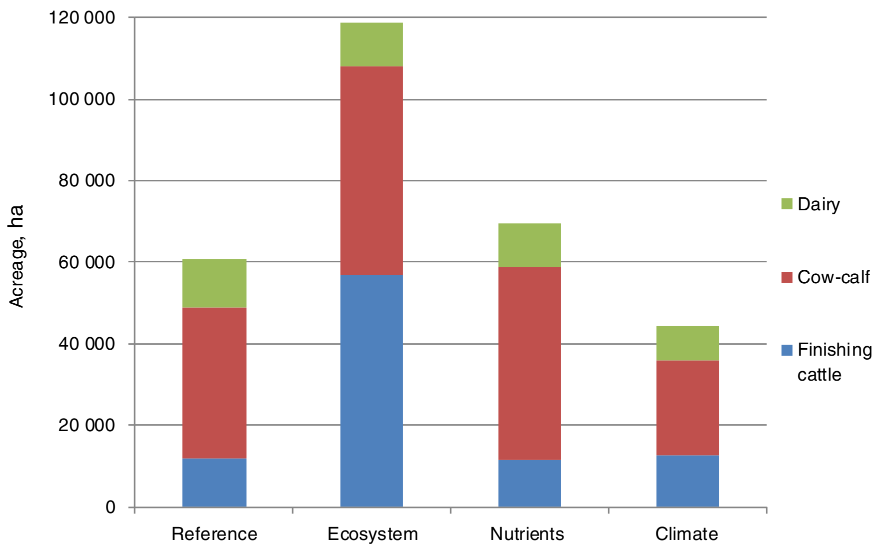

Fig. 5. Acreage of semi-natural pastures (ha) used by cattle in dairy and beef production in Västra Götaland county at present (Reference) and in the alternative scenarios Ecosystem, Nutrients and Climate.

Table 3
Sensitivity analysis of total global warming potential (100, 20 and 500 years of time perspective on impact), acidification (100, 50 and 25% efficiency of ammonia reduction measures) and marine eutrophication (100, 80 and 120% yield per hectare reflecting an inverse proportion of feed production emissions) from agricultural production, including inputs to agriculture, in Västra Götaland county in the alternative scenarios Ecosystem, Nutrients and Climate compared to present (Reference). Relative values, where 100 = total emissions for the Reference scenario for each category (dairy, beef and total).

	Global warming potential, time perspective on impact, years			Acidification, efficiency of ammonia reduction, %			Marine eutrophication, yield per hectare, %		
	100, baseline	20	500	100, baseline	50	25	100, baseline	80	120
Ecosystem									
Dairy	89	81	93	75	79	81	158	188	128
Beef	115	122	105	105	105	105	145	173	118
Total	100	97	99	86	88	90	152	181	123
Nutrients									
Dairy	78	75	79	37	43	46	98	116	79
Beef	80	81	78	64	73	77	98	117	80
Total	79	77	78	47	54	57	98	116	79
Climate									
Dairy	58	64	37	32	34	36	89	106	73
Beef	69	72	68	53	64	70	75	89	60
Total	63	67	51	39	45	48	82	98	67

Costs are slightly higher in the semi-forested district of Västra Götaland than in the plains district. Higher operating costs in the semi-forested district due to poor land consolidation are mainly offset by the compensatory allowance.

Within beef production, the environmental payment for grazing was important for the net cost of production (= sum of operational costs − environmental payment and animal premium). Fig. 7a shows the net cost of the various production models when all grazing occurred on semi-natural pasture, where one-third of the area received an additional environmental payment for high biodiversity values and two-thirds the basic payment. Fig. 7b shows the situation when two-thirds of the grazing occurred on semi-natural pasture with basic payment and one-third of the grazing was on arable land without environmental payment. In the first case with higher environmental payment, rearing models with steers and heifers in the Ecosystem scenario with much grazing (E D ∗ B steer G and E D ∗ B heifer G in Fig. 7a) competed very well with the best indoor bull models in terms of net costs in the Nutrients and Climate scenarios (N C D ∗ B bull I in Fig. 7a) in the former case (Fig. 7a), whereas the indoor bull models had the lowest cost in the latter case with low environmental payment for pasture (Fig. 7b). The D ∗ B models, where the calves were a “cheap by-product” of dairy cows, generally had lower net costs than beef models, where the production had to cover the entire cost of the suckler cow. Absolute values are presented in Tables S34–35.

The most cost-efficient production models in the future alternative scenarios had considerably lower net costs (35–40 SEK/kg) than the Reference scenario for suckler cow-based beef production (R Beef bull I in Fig. 7b; ~50 SEK/kg) and somewhat lower net costs than the current dairy breed-based beef production (R Dairy bull I; 41 SEK/kg).

4. Discussion

The main finding of the present analysis is that there is great potential to reduce environmental impact, resource consumption and production costs in the Swedish dairy and beef sectors, without affecting production volumes, by implementing existing knowledge and technology. This can be done regardless of whether ecosystem services, plant nutrient management or climate change is the focus and without impairing production economics. In order to interpret the results properly, there are a number of issues that should be noted. A main precondition in all scenarios is that the total production of milk and beef should be constant. It is important to keep in mind that production of cattle products does not cover domestic consumption and that greater domestic production would have been beneficial for the total impact on the environment from food consumption (Kumm and Larsson, 2007).

The results of the alternative scenarios reflect best farming practice of today, taken from the best quartile of Swedish farms. Hence, if all producers could achieve similar production results as today's best producers, a significant part of the improvement assumed here could be realised. However, we recognise that it is not easy to reach these production levels and it would require much of the single farmer and infrastructure to support this efficiency improvement. In order to improve the environmental performance of the Swedish cattle sector, it may be more effective to raise the performance of the 50% least efficient producers than to get the best to be even more effective. From an LCA research perspective, it is clear that the normal procedure of mainly working with averages results in important opportunities for improvement not being identified. This study had a supply chain approach dealing also with details in the production systems, contributing to an added value of the results.

The conclusion about the potential to reduce environmental impact

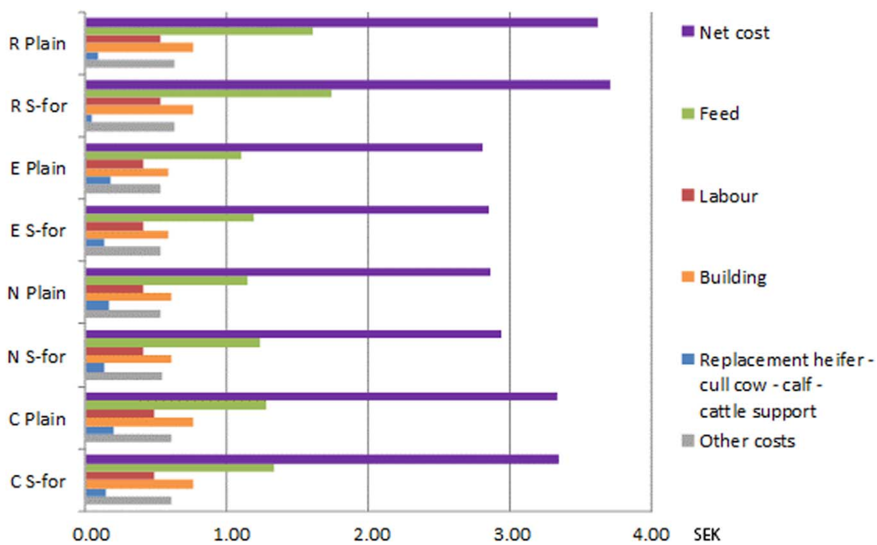

Fig. 6. Cost of production, SEK per kg energy-corrected milk (ECM). R is Reference; E (Ecosystem), N (Nutrients) and C (Climate) are the three alternative scenarios; Plain is plains district; S-for is semi-forested district. Other costs include bedding straw, insemination, veterinarian, medicine, energy and interest. Milk yield per cow is high in E and N, but moderate in C.

is valid also after having modified the data according to methodological uncertainties, effectiveness of technical means and uncertainty about crop yields. The largest uncertainty in the study is the crop yield and, hence, the acreage needed for feed production, influencing mainly marine eutrophication but also the other environmental impact categories. Although the yield as such is uncertain, the relationships among the Reference and the alternative scenarios still are valid. Also the analysis of diminishing the efficiency of ammonia reducing measures, shows these means are still important to reduce emissions. There is an ongoing discussion about using time perspective when calculating global potential warming (Pierrehumbert and Eshel, 2015). In the present study, the global warming potential for the cattle sector as a whole remained the same irrespectively of time perspective in use.

The calculated cost of production in both milk and beef production was significantly lower than it is in the current normal Swedish cattle production system according to Swedish University of Agricultural Sciences (2014). Thus, the profitability can be improved by using the production technology of the future scenarios. One can also ask why this productivity improvement is not made on purely economic grounds, i.e. why more producers are not as efficient as today's best, as

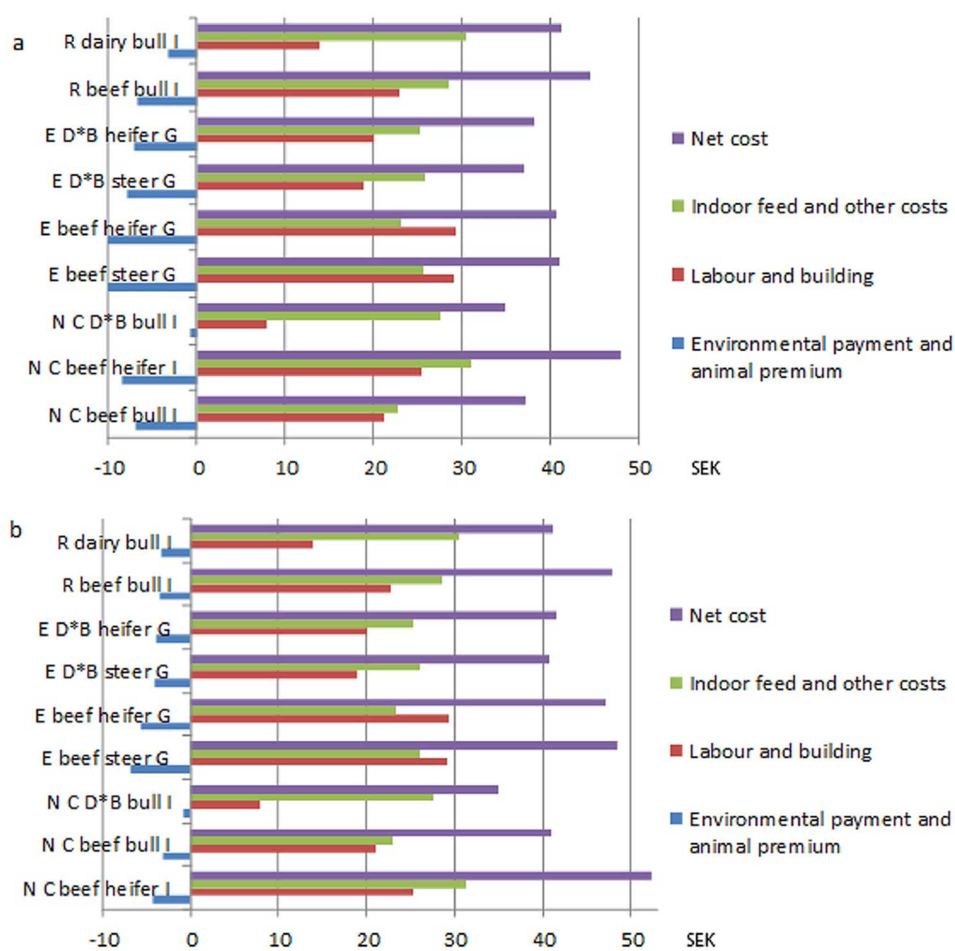

Fig. 7. Cost of production, SEK per kg carcass weight, when all grazing occurred on semi-natural pastures where a) one-third of the acreage received high and two-thirds basic payment or b) two-thirds of grazing occurred on semi-natural pastures with only basic environmental payment and one-third on leys without environmental payment. Calculated production costs (right-directed bars), environmental payment for grazing and premium to cattle over 1 year (left-directed bars) and net costs (uppermost right-directed bars in each alternative). R is Reference scenario; E (Ecosystem), N (Nutrients) and C (Climate) are the three alternative scenarios. D (Dairy), B (Beef) and D ∗ B (Dairy × Beef crossbred) are the breed of the calf; heifer and bull are the gender; I is indoor whole rearing of D and D ∗ B and indoor rearing after the suckling period for B. G is grazing during summer. For B, the costs of the dam are included. All production is in the semi-forested district.

this would mean higher profitability. Increased production efficiency often requires large investments and great knowledge. For beef, much of the production is carried out on a part-time basis and often with existing buildings and other resources. It can therefore continue at low profitability, at least in a short-term perspective. In larger operations, streamlining requires major economic investment, which may be regarded by farmers as too risky. Moreover, economics cannot predict human behaviour, as people are guided by reasons, not causes (Röling, 1997). To be implemented, new techniques and knowledge must fit into the farmer's actual context. There are currently several agricultural decision support systems facilitating sustainable farming. However, to create successful hardware, progress must be regarded as an interactive learning process, where the technology is embedded in cooperation with its future users and their context (Lundström et al., 2016).

The potential for environmental improvement of dairy production and beef production has to be analysed simultaneously, as the systems are connected to each other. This was concluded in principle by Cederberg and Stadig (2003), but has rarely been applied in later LCAs of beef and dairy. Designing alternatives for more efficient dairy production without taking into account how these affect beef production, or vice versa, may produce sub-optimal alternatives. By increasing the production efficiency of dairy production, a need arises for increased suckler cow-based beef production to maintain beef product volume. This beef production has a higher environmental impact in several categories, but also contributes positively to other environmental aspects such as biodiversity through its management of semi-natural pastures. Therefore, in order to comment on the environmental impact of different dairy production systems, the changes in beef production have to be included in the discussion. This was partly shown in a study by Marton et al. (2016), where different methods for allocation and systems expansion were applied. It was found that when systems expansion was used, the impact per kg of milk was lower than when economic- or mass-based allocation was used. In the present study, time perspective influenced proportion of global warming potential originating from dairy and beef, respectively. Taken together this reinforces our conclusion that the two systems need to be assessed simultaneously. On a more specific level, it is important not to study the environmental impact of individual crops or other details. In designing the alternative scenarios, the ambition was to improve the system performance in the whole crop rotation.

Marine eutrophication increased for milk in the Ecosystem scenario (Fig. 3), as a result of using a large share of domestically produced protein feed, which caused more nitrate leaching than imported or by-product-based feeds. This choice of feed was positive for the environmental impact in feed production, through reduced use of pesticides, but this mainly resulted in reduced impacts for products not included in this study. This is a good example of the difficulties in designing and analysing agricultural production systems; the systems are large and interconnected, which makes it difficult to distinguish the consequences for single products.

As found in several previous studies (e.g. Roer et al., 2013; Mogensen et al., 2015), the feed was the single most important parameter for the environmental results. Working effectively with feed issues requires taking a comprehensive approach to efficiency, diet formulation and cropping. To increase the efficiency of the animals, in all the scenarios we used the new technique of sex-sorted semen for the dairy cows, which enables a large proportion of beef breed semen to be used in the dairy herd without compromising the number of replacement heifers. The growing dairy × beef crossbred cattle had a higher feed efficiency than purebred dairy calves. Designing targeted diets is the next step in streamlining. For suckler cows, this is about reducing overfeeding by providing more fibre-rich roughages than is often the case today, whereas dairy cows and growing cattle need to get more digestible, earlier harvested, forages than may be offered today. Thereafter, the diets can be adjusted based on the environmental impact of the individual feeds and then the feed ration formulations should interact with plant cultivation to design appropriate crop rotations. It is often possible to change some components in the diet to allow for better crop rotations that provide environmental benefits, which may be different depending on the environmental objectives in focus. Finally, we found large gains in reducing wastage, especially in primary production. Examples of wastage that can be reduced are harvest and storage losses of forages, animal mortality and losses of gaseous nitrogen in manure handling. Therefore, increased production efficiency requires identification of such "invisible" costs of wastage.

Technical alternatives which had an effect on the county system level included different ways to use the relatively large volumes of by-products generated. In the Climate scenario, it was assumed that most animal by-products were used for biogas production, with return of the digestate to agriculture and use of the biogas as fuel. This provided benefits for the energy balance and also decreased the influx of new phosphorus to the system. Combustion of by-products with recovery of phosphorus from ash also provided benefits, but as the nitrogen in the by-products was lost, the energy balance was not as high as with digestion. In this project, costs for these systems were not included, which is a limitation of the study.

Some of the costs for achieving the alternative scenarios were not included in the cost calculations. One example is the increased need for production monitoring (feed analysis, weighing of animals, etc.). Another example is the need to acquire knowledge of production biology and enterprise management. This can be achieved through education, procurement of advisory services or increased cooperation and specialisation in different areas of production.

Our results show that there are a number of critical conflicts between environmental objectives, meaning that measures to strengthen some environmental impact categories cause deterioration for others. An example of conflicts is that between management of semi-natural pastures, which is important for biodiversity and ecosystem services, and impact on global warming potential. On county level, the main reason for the conflict between the Ecosystem and Climate scenarios was the higher proportion of proper grazing, with more methane-emitting, suckler cow-based beef production in the former than in the latter, whereas the proportion of dual-purpose dairy cows was higher in the Climate scenario. Conflicts also emerged on herd level. In order to manage large areas of semi-natural pastures, cattle were required to graze during the growing period and eat a similar forage-based diet during the winter. To facilitate pasture management, grazing male cattle had to be castrated and raised as steers, although steers have a lower feed efficiency than intact bulls. Taken together, this pasture-based production system resulted in a lower weight gain and, hence, a higher global warming potential per kg of beef than an intensive system (Mogensen et al., 2015). However, the use of semi-natural pastures could reduce greenhouse gas emissions, directly as increased carbon sequestration in soils and indirectly as reduced indirect land use resulting from use of concentrate feeds, mainly soy. Battini et al. (2016) showed that these indirect emissions constituted 20 to 35% of total greenhouse gas emissions in the four dairy systems studied.

In the Ecosystem scenario, the use of calves from dairy production was intensified by using beef breed sires and decreasing mortality, which was combined with raising the male calves as steers. Overall, this scenario resulted in unchanged global warming potential but twice the area of semi-natural pastures being managed. In fact, beside preserving all managed pasture land in the county of Västra Götaland today, previously used overgrown pasture could be restored and managed. However, when beef production was intensified, as in the Climate scenario, the global warming potential was even lower, both overall and per kg of beef, but the area of semi-natural pastures decreased. Similar results were reported by Peters et al. (2010), who showed that intensification decreased environmental impacts per unit produced and used less land. In the alternative scenarios, most conflicts were between the Ecosystem scenario and the other two scenarios, whereas there were only a few conflicts between the Nutrients scenario and the Climate scenario. Therefore, it would be possible to combine these two alternative scenarios without having to make serious compromises between environmental objectives.

5. Conclusions

There is great potential to reduce the negative environmental impact of Swedish dairy and beef production while maintaining production volumes and decreasing the costs of primary production, with the single most important factor being increased production efficiency. An integrated approach to environmental assessments of dairy and beef is necessary to avoid the risk of suboptimal solutions, since the two systems are strongly interconnected. Including economic efficiency increases the value of studies focusing on environmental improvements, as no agricultural system can be sustainable in the long run unless based on sound economics.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.agsy.2017.06.004.

References

Battini, F., Agostini, A., Tabaglio, V., Amaducci, S., 2016. Environmental impacts of different dairy farming systems in the Po valley. J. Clean. Prod. 112, 91–102.
Cederberg, C., Stadig, M., 2003. Systems expansion and allocation in life cycle assessment of milk and beef production. International Journal of LCA 8, 350–356.
Ecoinvent Centre, 2013. Ecoinvent Data, Version 3.0. Ecoinvent Reports No. 1-25. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.
European Commission, 2011. Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - Recommendations for Life Cycle Impact Assessment in the European Context. First Edition November 2011. EUR 24571 EN. Publications Office of the European Union, Luxemburg.
Flysjö, A., Henriksson, M., Cederberg, C., Ledgard, S., Englund, J.-E., 2011. The impact of various parameters on the carbon footprint of milk production in New Zealand and Sweden. Agric. Syst. 104, 459–469.
Frischknecht, R., Jungbluth, N., 2003. Implementation of Life Cycle Impact Assessment Methods. Final Report Ecoinvent 2000. Swiss Centre for LCI, Duebendorf, Switzerland.
IPCC, 2006. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), IPCC Guidelines for National Greenhouse Gas Inventories – Volume 4. Agriculture, Forestry and Other Land Use. Chapter 10 and 11. Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan Published:.
IPCC, 2007. IPCC Climate Change Fourth Assessment Report: Climate Change 2007. Retrieved 17 01 17 from. http://www.ipcc.ch/ipccreports/assessments-reports.htm.
Johnsson, S., Kumm, K.-I., Jeppsson, K.-H., Lidfors, L., Lindén, B., Pettersson, B., Ramvall, C.-J., Schönbeck, P., Törnquist, M., 2004. System för nötköttsproduktion (Systems for Beef Production). Report 5. Department of Animal Health and Environment, Swedish University of Agricultural Sciences (in Swedish).
Kumm, K.-I., Larsson, M., 2007. Import av kött – export av miljöpåverkan (Import of Meat – Export of Environmental Impact). Report 5617. Swedish Environmental Protection Agency (in Swedish).
Liljeholm, J., Bertilsson, J., Strid, I., 2009. Närproducerat foder till mjölkkor - miljöpåverkan från djur (Locally Produced Feeds to Dairy Cows – Environmental Impact From Animals). Report 273. Department of Animal Nutrition and Management, Swedish University of Agricultural Sciences (in Swedish).
Lindgaard Jensen, M., 2011. Gylleforsuring i kvægstalde: erfaringer fra 15 kvægbrugere der bruger svovlsyrebehandlingsanlæg (Manure Acid Treatment in Dairy Stalls: Experiences From 15 Cattle Farmers Using Sulfuric Acid Treatment). Farm Test Kvæg No. 66. Videncentret for Landbrug, Kvæg, Danmark (in Danish).
Lundström, C., Lindblom, J., Ljung, M., Jonsson, A., 2016. Sustainability as a governing principle in the Use of agricultural decision support systems: The case of CropSAT. IFSA Symposium, Newport, UK.
Marton, S.M.R.R., Zimmermann, A., Kreuzer, M., Gaillard, G., 2016. Comparing the environmental performance of mixed and specialized dairy farms: the role of systems level analyzed. J. Clean. Prod. 124, 73–83.
Mogensen, L., Kristensen, T., Nielsen, N.I., Spleth, P., Henriksson, M., Swensson, C., Hessle, A., Vestergaard, M., 2015. Greenhouse gas emissions from beef production systems in Denmark and Sweden. Livest. Sci. 174, 126–143.
Nelson, B.-O., 2002. Modell för beräkning av lönsamheten i nötköttsproduktionen (Model for Calculation of Profitability in Beef Production). SLA's Group of Analyses, Ängelholm (in Swedish).
NorFor Nordic Feed Evaluation System, 2008–2012. Typfoder Version 5.8b. Swedish Dairy Association.
Peters, G.M., Rowley, H.V., Wiedemann, S., Tucker, R., Short, M.D., Schulz, M., 2010. Red meat production in Australia: life cycle assessment and comparison with overseas studies. Environ. Sci. Technol. 44, 1327–1332.
Pierrehumbert, R.T., Eshel, G., 2015. Climate impact of beef: an analysis considering multiple time scales and production methods without use of global warming potentials. Environ. Res. Lett. 10, 085002.
Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J.A., 2009. A safe operating space for humanity. Nature 461, 472–475.
Roer, A.-G., Johansen, A., Bakken, A.K., Daugstad, K., Fystro, G., StrØmman, A.H., 2013. Environmental impacts of combined milk and meat production in Norway according to a life cycle assessment with expanded system boundaries. Livest. Sci. 155, 384–396.
Röling, N., 1997. The soft side of land: socio-economic sustainability of land use systems. ITC Journal 3, 248–262.
Seuring, S., Müller, M., 2008. From a literature review to a conceptual framework for sustainable supply chain management. J. Clean. Prod. 16, 1699–1710.
SimaPro 7, 2007. PRé Consultants B.V. Amersfoort. The Netherlands. Retrieved 04 05 14 from. www.pre.nl.
Sonesson, U., Lorentzon, K., Andersson, A., Barr, U.-K., Bertilsson, J., Borch, E., Brunius, C., Emanuelson, M., Göransson, L., Gunnarsson, S., Hamberg, L., Hessle, A., Kumm, K.-I., Lundh, Å., Nielsen, T., Östergren, K., Salomon, E., Sindhöj, E., Stenberg, B., Stenberg, M., Sundberg, M., Wall, H., 2015. Paths to a sustainable food sector - integrated design and LCA of future food supply chains, the case of pork production in Sweden. International Journal of LCA. http://dx.doi.org/10.1007/s11367-015-0969-5.
Spörndly, R., 2003. Fodertabeller för idisslare (Feed Tables for Ruminants). Report 257. Department of Animal Nutrition and Management, Swedish University of Agricultural Sciences Retrieved 14 11 14 from. www.slu.se/institutioner/husdjurens-utfodring-vard/Verktyg/fodertabell-for-idisslare (in Swedish).
Statistics Sweden, 2014. Agricultural Statistics 2013. Retrieved 15 11 14 from. www.scb.se.
Swedish Board of Agriculture, 2013. Stank in Mind, Version 1.20. Retrieved 10 12 13 from. www.jordbruksverket.se/amnesomraden/odling/vaxtnaring/berakningsverktygetcofoten/omstankinmind.4.6beab0f111fb74e78a78000102.html (in Swedish).
Swedish Board of Agriculture, 2015. Jordbruksstöden 2015 (Agricultural Supports 2015). Retrieved 30 12 15 from. www.jordbruksverket.se/amnesomraden/stod/jordbrukarstod2015.4.53b6e8e714255ed1fcc71bd.html (in Swedish).
Swedish Dairy Association, 2012. Cattle Statistics. (37 p).
Swedish Environmental Objectives Council, 2008. Sweden's environmental objectives - no time to lose, p 198. Swedish Environmental Protection Agency, Stockholm.
Swedish Species Information Centre, 2015. Rödlistade arter i Sverige 2015 (Redlisted Species in Sweden 2015). Swedish Species Information Centre, Swedish University of Agricultural Sciences Retrieved 15 11 16 from. www.artdatabanken.se (in Swedish with English summary).
Swedish University of Agricultural Sciences, 2014. Områdeskalkyler och Databok (Area Calculations and Data Book). Published every year. Retrieved 01 10 14 from. www.agriwise.org (in Swedish).
Taurus, 2013. Slaughter Statistics Year 2012. Retrieved 01 10 13, from. www.taurus.mu (in Swedish).
Vera, F.W.M., 2000. Grazing Ecology and Forest History. CABI Publ., Wallingford, UK.