Producing oat drink or cow's milk on a Swedish farm – environmental impacts considering the service of grazing, the opportunity cost of land and the demand for beef and protein

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Abstract

There are plant-based alternatives to cow's milk that resemble milk in appearance and function, but differ nutritionally. These are associated with lower land use and environmental impact than milk. However, there are places where dairy herds contribute positively to conservation of high nature value pastures through their grazing. The dairy system also produces meat, but it can be questioned how much beef is needed/demanded. This study evaluated the environmental impact of production of oat drink in comparison with production of milk in terms of: i) the necessity for sufficient grazing animals in the landscape for biodiversity conservation; ii) different perspectives on the need for beef and protein; iii) the opportunity cost of land; and iv) the differing protein content of milk and oat drink. The climate impact, eutrophication and acidification potential and ecotoxicity impacts of a typical Swedish dairy farm were calculated and compared with those of the same farm when milk production was replaced by production of oat drink and three different alternatives to dairy beef: 1) beef from suckler herds; 2) chicken; and 3) plant-based protein. In all scenarios, the same area of semi-natural grassland was grazed. The opportunity cost of land use was included by producing bioenergy on spare land. The direct greenhouse gas emissions were considerably lower (16-41%) for all oat drink scenarios than for the milk scenario. When the bioenergy produced on the spare land was assumed to replace diesel, this substitution effect cancelled out the direct emissions almost entirely when chicken or plant-based protein was produced instead of beef. The eutrophication potential was similar for all scenarios, while the acidification potential was 21-37% higher in the oat drink scenarios due to the need for handling increased amounts of digestate from bioenergy (biogas) production. This explorative study demonstrated great potential for reduced climate impact through production of oat drink instead of cow's milk, while still preserving grazing services for biodiversity conservation. However, for this to happen, incentives to manage semi-natural grassland need to be introduced, as such management is not an inherent effect of oat drink production. In addition, for the environmental benefits demonstrated in this study to come about, consumers must be incentivised to consume oat drink instead of milk and, to achieve the largest climate impact reductions, to replace some beef with chicken or cereals and legumes.

Keywords: oat drink, milk, climate impact, protein, opportunity cost, grazing, environmental impact

1. Introduction

Evidence is mounting that current food production systems are unsustainable in several ways and need substantial improvements (Godfray et al., 2010). Apart from production measures such as more efficient use of energy, fertilisers and water and closure of yield gaps (Burney et al., 2010; Foley et al., 2011; Mueller et al., 2012), changes in consumption patterns are also necessary, as the growing demand for more resource-demanding food products by the world's increasingly wealthier populations is cancelling out production-side efficiency gains (Bajželj et al., 2014; Foley et al., 2011; Smith, 2014). Meat and dairy are among the food products which cause most emissions of greenhouse gases and feeding crops to animals is considered inefficient, leading to large land and other resource requirements for feed production (Nijdam et al., 2012).

Milk and other dairy products are consumed in large amounts in a number of developed countries and consumption is rapidly increasing in other low and middle income countries (Gerosa & Skoet, 2012). There are several plant-based alternatives to cow's milk that resemble milk in appearance (Mäkinen et al., 2015) and can be considered partly functionally equivalent, i.e. a white drink to consume cold or warm with cereals, porridge, tea or coffee, or to be processed into different products resembling yoghurt, ice-cream etc. These plant-based substitutes for milk are water-soluble extracts of legumes, oilseeds, cereals or nuts. Although studies on the environmental impact of production of these milk alternatives are scarce, the results available indicate that e.g. the climate impact per unit weight of product from the production of these is considerably lower than for cow's milk due to the avoided emissions from animals, manure and feed production (Mäkinen et al., 2015). The avoidance of emissions from manure and feed production also leads to smaller contributions to acidification, eutrophication and water stress.

Apart from dairy production using considerably more land than the production of plant-based alternatives, its production differs in other fundamental ways that affect comparison of the environmental impact of milk and milk alternatives. One important aspect is that apart from milk, a dairy system also delivers several other outputs, of which two important products in a developed world context are beef and grazing services supporting various ecosystem services (Robert Kiefer et al., 2015). The multifunctional aspect of dairy production delivering both milk and meat is handled in current life cycle assessments through either: 1) allocation, in which the total impact from the milk production system is divided between the milk and the meat based on physical or economic relationships, and 2) system expansion, in which (most commonly) the impact from a pure beef production system is subtracted from the total impact of the dairy production system (Flysjö et al., 2011). Most studies use other beef as a substitute for the beef produced through dairy production, although one study considered that pork or poultry meat could replace some of the beef from dairy production (Flysjö et al., 2011). Depending on the function of beef for the consumer – as providing a sense of pleasure, as a status marker that only beef or other meat can provide or as providing protein and other essential nutrients, the beef from dairy production could be replaced by different types of meat, fish, cheese or plant-based protein sources made from legumes and cereals.

To our knowledge, the grazing services that animals in dairy production systems can provide have not been considered previously in quantitative environmental assessments of milk. In many countries, dairy cows and their offspring contribute positively to the conservation of high nature value pastures through their grazing, which prevents the areas from becoming reforested. Reforestation threatens the many meadow species that have adapted to the low-intensity agricultural management of grazing land carried out over hundreds of years (Hampicke & Plachter, 2010). In Sweden, 35% of the utilised biomass from semi-natural grassland is consumed by dairy cows and their offspring (Röös et al., 2015). Grazing is a service that does not inherently follow the production of plant-based milk alternatives but dairy cows are also not a prerequisite for pasture management, as these areas can be grazed by suckler herds, sheep or horses, or managed manually or mechanically (Carlsson et al., 2014) in parallel with the production of plant-based milk alternatives. Hence, a system that delivers both a plant-based milk alternative and grazing services could be designed in a multitude of ways.

The difference in nutritional quality between cow's milk and plant-based alternatives is another important aspect which needs to be considered in comparisons of the environmental impact of the two. Drewnowski et al. (2015) suggest a method to compare the environmental impact from different food products based on the functional unit of nutrient density instead of mass. The nutrient density score is calculated based on an algorithm to include some specific nutrients. However, the usefulness of this method when it comes to comparing individual food products can be questioned, as (Western) diets consist of hundreds of different food products and it is the contribution of all these to the nutritional profile of the complete diet that is of interest. For example, milk is an important contributor of protein, calcium and vitamins A, B₂ and B₁₂ in the Western diet, but these nutrients can be supplied by a combination of fortified and plant-based foods (Craig, 2009). The nutrient content of plant-based milk alternatives differs between types of drink. Apart from soy drink, most are low in protein (oat drink 0.4-1% protein, rice 0.1-0.2%, almond drink 0.5% of protein) in comparison with cow's milk (3.3-3.4%) (Mäkinen et al., 2015). The fat and total energy content are also lower (Mäkinen et al., 2015), but can be compensated for by the addition of vegetable oil. As regards micronutrients, several milk alternatives are produced in fortified versions to be comparable to cow's milk. Therefore, the difference in protein content is one of the most important aspects to consider. However, protein consumption in most developed countries is well above the recommended level (Westhoek et al., 2011) and it could be argued that a general decrease in total protein consumption is needed to alleviate environmental pressures from the food system.

Most life cycle assessments of foods do not consider the opportunity cost of using land, i.e. alternative land uses and the cost for not using land for these other purposes. This was highlighted by Garnett (2009), who argued that considering the global constraints on land, the opportunity cost of rearing livestock instead of growing food for direct human consumption must be considered when assessing the sustainability of different foods.

Hence, the purpose of this study was to evaluate the environmental impact of production of a plant-based alternative to cow's milk, here oat drink from Sweden, and compare it with the environmental impact of production of cow's milk. This was done using a set of scenarios that considered: i) the necessity for grazing animals in the landscape for biodiversity conservation; ii) different perspectives on the need for beef and protein; iii) the opportunity cost of land; and iv) the differing protein content of cow's milk and oat drink.

2. Method

2.1 Overview and scenarios

In this study the environmental impacts of a typical fictional Swedish dairy farm (100 dairy cows) (the REF scenario) were calculated using a life cycle perspective. These impacts were compared with those of the same farm when dairy production was replaced by cultivation of oats and oilseed rape for production of the same amount of oat drink and three different alternatives to the dairy beef. These alternatives were: 1) beef from suckler herds (scenario BEEF), based on the assumption that beef could only be replaced by beef; 2) chicken (scenario CHICK), based on the current trend of increasing poultry meat consumption and decreasing beef consumption in the EU (FAO, 2015); and 3) plant-based protein, i.e. a combination of cereals and grain legumes (scenario PLANT) based on the increasing trend of vegetarianism, showing that plant-based protein sources are a valid substitute for meat among some population groups. The oat drink recipe came from the Swedish company Oatly. For the production of 1 kg of oat drink, 0.20 kg of harvested oats and 0.035 kg of rapeseed oil were needed, which yielded an oat drink with a fat concentration equivalent to that of average Swedish cow's milk (4.2% as it leaves the cow; Växa Sverige, 2013) and a protein content of 1% (Florén et al., 2013) .

The farm consisted of 336 hectares of agricultural land, of which 15% (49 ha) was assumed to be semi-natural grassland and the rest arable land. This ratio of semi-natural grassland/total agricultural land corresponds to the ratio for the whole of Sweden (SBA, 2013). Semi-natural grassland is currently the most threatened habitat in Sweden and its continued maintenance through low-intensity grazing, preventing reforestation or rewilding, is crucial for reaching national goals on biodiversity conservation (Eide, 2014). Hence, in order to consider the need for grazing livestock on semi-natural grassland, in all scenarios, including those in which no milk was produced, the 49 ha of semi-natural grassland were assumed to be grazed by cattle and some beef was produced in all scenarios.

To account for the opportunity cost of land, it was assumed that the land saved on the farm, i.e. not needed to produce feed or food, was used for grass-clover cultivation and the grass-clover biomass was used for biogas production together with manure (including straw used for bedding) and slaughter waste. A grass-clover crop was chosen as the energy crop in order for the crop rotations in the different scenarios to be as similar as possible (making the scenarios as comparable as possible). In addition, there are limitations to how often some annual crops should be grown in the crop rotation. For example, rapeseed (for biodiesel) should not be cultivated more often than every 5-6 years due to soil-borne fungal diseases.

The biogas was assumed to be used on the farm for tractor fuel and the production of ‘green’ synthetic nitrogen fertiliser (Ahlgren et al., 2010) to complement the digestate from the biogas production and the production of heat and electricity (Kimming et al., 2011), making the farm self-sufficient in energy and fertiliser. Potential additional biogas was exported from the farm and was assumed to replace diesel on other farms or in other sectors, hence providing a climate benefit by avoided fossil fuel combustion (Albanito et al., 2015). All animal production systems were constructed so that the farm was self-sufficient in feed, excluding additional mineral and vitamin feed ingredients. However, the latter constitute a minor part of feed and were hence omitted from the analysis (Cederberg et al., 2009a). The only resources that needed to be imported continuously to the farm were some mineral phosphorus and potassium fertilisers, pesticides and medicines.

To account for the different protein content in cow’s milk and oat drink, as well as the different views on the need for protein, the BEEF, CHICK and PLANT scenarios were complemented with three additional ‘high-protein’ (HP) scenarios, BEEF-HP, CHICK-HP and PLANT-HP, in which the farm produced the same amount of protein in total as the dairy farm, by additional production of cereals and grain legumes. The number of animals on the farm in the different scenarios and the products generated are summarised in Table 1.

2.2 Functional unit and system boundaries

All products leaving the farm were included in the functional unit to avoid allocation of impacts between products, which was not necessary considering the purpose of this study. To make the scenarios comparable in terms of output apart from the milk/oat drink and beef/alternatives to beef, in all scenarios rapeseed oil and protein feed were also produced. The rapeseed oil was an output from the reference scenario as a consequence of the dairy cows consuming rapeseed cake as a protein feed. In the alternative scenarios with oat drink production, rapeseed oil needed to be produced as it is an ingredient in oat drink. However, in these scenarios additional rapeseed oil was produced, so that the total amount of rapeseed oil leaving the farm (apart from that included in the oat drink) was equivalent to that in the reference scenario (Table 1). From the production of the rapeseed oil in the oat drink scenarios, rapeseed cake was produced and from the production of oat drink a by-product called ‘oat-slurry’ was produced. Both rapeseed cake and oat-slurry are valuable protein feeds, so for the REF scenario to be comparable to the oat drink scenarios, equivalent amounts of protein feed needed to be produced in the REF scenario, which was done through the cultivation of grain legumes. In summary, all scenarios delivered either cow’s milk or oat drink, beef (including offal and blood) and/or an alternative (chicken or plant-based protein), rapeseed oil and protein feed (Table 1). The HP scenarios also produced additional cereals and grain legumes in order to provide the same amounts of protein in total from the oat drink scenarios as from the dairy REF scenario. Hence, the scenarios BEEF, CHICK and PLANT can be compared against the REF scenario using the following functional unit:

- The production of 880 tonnes of a drink with the function of milk *and an additional amount of 5 tonnes of protein for human consumption*, 14 tonnes of rapeseed oil and

protein feed corresponding to 142 tonnes of grain legumes, as well as the grazing of 49 ha of semi-natural grassland.

The scenarios BEEF-HP, CHICK-HP and PLANT-HP can be compared against the REF scenario using the following functional unit:

- The production of 880 tonnes of a drink with the function of milk *and a total amount of 35 tonnes of protein for human consumption*, 14 tonnes of rapeseed oil and protein feed corresponding to 142 tonnes of grain legumes, as well as the grazing of 49 ha of semi-natural grassland.

The system boundary was set at the farm gate apart from the use of energy to produce the oat drink at the factory and the energy needed in dairy industries, which was included in order to account for differences between milk and oat drink in this step. Production and maintenance of capital goods and production and transport of mineral phosphorus and potassium fertilisers, pesticides, mineral and vitamin feeds and fortification products and medicines were not included, as previous studies have shown that they make a low contribution to the overall impact in these types of production systems (Bernesson et al., 2006; Röös et al., 2011). As all scenarios use the same amount of land and since the purpose was to compare cow's milk and oat drink production, rather than establishing absolute numbers for these products per kg of product, it was not necessary for the purposes of this study to include indirect effects of land use.

Table 1. Number of animals on the farm in the different scenarios and the resulting products.
Differing values for HP scenarios are given in brackets.

	REF	BEEF (BEEF-HP)	CHICK (CHICK-HP)	PLANT (PLANT-HP)
Product replacing part of the dairy beef in the reference scenario	-	Beef from suckler herds	Chicken	Cereals and grain legumes
Number of animals on the farm				
Dairy cows	100 ¹	0	0	0
Suckler cows	0	95 ²	49 ³	49 ³
Total cattle	286	272	140	140
Broiler chickens	0	0	10594	0
Products leaving the farm (ton)				
Dairy milk	880	0	0	0
Oat drink	0	880	880	880
Rapeseed oil	14	14	14	14
Beef, bone-free	20	20	10	10
Chicken, bone-free	0	0	11	0
Offal and blood	3.2	3.2	1.6	1.6
Cereals, food-grade	0	0 (74)	0 (73)	15 (88)
Grain legumes, food-grade	0	0 (69)	0 (69)	5.6 (75)
Protein feed exported	142 ⁴	142	142	142
Total protein	35	14 (35)	14 (35)	14 (35)

¹Number of dairy cows set to represent an typical dairy farm in Sweden.

²Number of suckler cows determined by the need to produce as much beef in this scenario as in the reference scenario.

³Number of suckler cows determined by the amount of semi-natural grassland available for grazing.

⁴Corresponding amount in grain legumes. In order to replace rapeseed cake with grain legumes, 38% more legumes are required. The corresponding figure for oat slurry is 19% (calculated based on crude protein content only).

2.3 Production data

The production systems modelled in this study build on data from current Swedish production systems for plant and animal production, with the exception that the farm is self-sufficient in feed, as well as energy and fertiliser through biogas production (Cederberg et al., 2009a). A comprehensive description of all production parameters, sources etc. is given in Rööf et al. (2015) and they are only briefly summarised here. Parameters for plant production are shown in Table 2. The use of the land on the farm for different purposes and the yearly distribution of crops grown on the arable land are shown in Fig. 1. In the REF, CHICK and CHICK-HP scenarios land is needed for the production of protein feed exported (Table 1) while in the other scenarios the protein feed exported is a by-product from oat drink production (oat slurry and rape seed cake) and no additional land for its production is needed.

Table 2. Yearly yield, fertiliser use and fuel energy for the plant production system modelled in this study (Rööf et al., 2015)

	Grass-clover for harvest	Grass-clover for pasture ¹	Cereals for feed	Rape seed	Legumes for feed	Oats	Cereals for food	Legumes for food
Yield ² , ton/ha	7600	4500	4000	2500	2800	5300	5200	1600
Fertiliser, kg/ha								
- Nitrogen	150	90	80	120	0	100	150	0
- Phosphorus	15	15	20	25	15	20	20	15
- Potassium	150	150	30	40	35	30	30	35
Fuel energy, GJ/ha	1.5 ³	1.5 ³	3.1	3.2	3.1	3.1	3.1	3.1

¹Grass-clover crop as part of the crop rotation used for grazing.

²Net yield after deduction for seed.

³Average for a three-year grass-clover crop.

Fig. 1. Use of agricultural land for different purposes on the farm (a) and crops grown on the farm's arable land (b) as a consequence of the number of animals kept on the farm and their feed requirements and the plant-based foods needed to replace animal products in the alternative scenarios (Table 1). In the BEEF scenario, beef from suckler herds replaced the beef from the dairy production, in the CHICK scenario chicken replaced dairy beef and in the PLANT scenario a mixture of cereals and grain legumes replaced dairy beef. In scenarios ending with HP, the farm produced the same amount of protein in total as the dairy farm, by additional production of cereals and grain legumes.

In the REF scenario, milk was produced in a modern dairy system, with a milk yield of 8800 kg energy corrected milk (ECM) per cow and year delivered from the farm (see Table 3 for other production parameters). Dairy cows and their offspring, which are reared for recruitment and for meat, were fed silage and pasture, cereals, rapeseed cake and grain legumes that are produced on the farm (Table 4). Of the dairy cows' intake of grazed biomass, 10% was assumed to come from semi-natural grassland (restricted by the necessity of keeping dairy cows close to the milking facilities), while the corresponding figure for heifers and steers was 50%. For security reasons, bulls (80% of male offspring) were not kept on semi-natural grassland.

In the BEEF, CHICK and PLANT scenarios, suckler herds of beef breeds were used to graze the semi-natural grassland. Cows, heifers and steers received 50% of their feed intake during the grazing season from semi-natural grassland, while bulls were raised entirely on feed

grown on arable land (see Table 3 for other production parameters). Winter feed in the form of silage, cereals and grain legumes was produced on the farm (Table 4).

In the CHICK scenario, chickens were raised to a live weight of 2 kg in 36 days, requiring 1.8 kg of feed per kg of live weight. The feed consisted of 50% cereals, 25% rapeseed cake and 25% grain legumes. Energy use was set to 0.5 MJ electricity and 2.8 MJ of heat per animal, based on a previous study (Hörndahl & Neuman, 2012). As regards energy use on the farm for ruminant production, it was assumed that 0.5 MJ of electricity per kg of milk produced was needed for milking machinery, lighting, cooling etc. (Flysjö, 2012), while for suckler production energy consumption was set to 230 MJ per animal (Edström et al., 2005).

Table 3. Parameters describing the ruminant production systems modelled in this study (Röös et al., 2015)

	REF scenario (milk production)	BEEF, CHICK and PLANT scenario (suckler beef production)
Milk yield, kg ECM per cow and year (delivered)	8,800	Na
Recruitment rate, %	38	20
Calves per cow and year, %	0.95	0.95
Mortality rate calves, %	2	2
First calving at age, months	28	28
Male offspring raised as steers, %	20	20
Manure system (most common system in Sweden chosen)	Slurry for female animals, deep litter for males	Deep litter

Table 4. Feed consumption in the ruminant production systems modelled in this study. For dairy and suckler cows, feed consumption is per year. For heifers, bulls and steers, feed consumption is per lifetime. From Stabo (2012a, 2012b).

REF scenario (milk production)				
	Dairy cow	Heifer	Bull	Steer
Slaughter age, months	60	23	18	24
Slaughter weight, kg	290	290	320	320
Forage, kg dry matter	4100	3600	2000	4000
Cereals, kg	1900	80	1060	60
Rapeseed cake, kg	250	0	0	0
Legumes, kg	310	60	480	60
Ratio of pasture on semi-natural grassland, %	10	50	0	50
Days on pasture per year	90	150	0	150
BEEF, CHICK and PLANT scenarios (suckler production)				
	Suckler cow	Heifer	Bull	Steer
Slaughter age, months	88	22	15	19
Slaughter weight, kg	320	320	320	320
Forage, kg dry matter	3100	3800	2000	3200
Cereals, kg	100	180	1020	240
Rapeseed cake, kg	0	0	0	0
Legumes, kg	0	160	420	160
Ratio of pasture on semi-natural grassland, %	50	50	0	50
Days on pasture per year	150	150	0	150

Energy use in the dairy industry was set to 0.42 MJ electricity and 0.60 MJ of gas per kg of milk and the corresponding values for the production of oat drink were 0.49 and 1.17 MJ (Florén et al., 2013).

2.4 Calculation of environmental impacts

The overall aim of this study was to evaluate the environmental impact in relation to six of the 16 environmental quality objectives (SEPA, 2015) adopted by the Swedish Parliament according to their relevance for agricultural production. These objectives were Reduced Climate Impact, Natural Acidification Only, Zero Eutrophication, A Non Toxic Environment, A Varied Agricultural Landscape and A Rich Diversity of Plant and Animal Life. The climate impact was calculated using the Global Warming Potential with characterisation factors for methane and nitrous oxide of 34 and 298, respectively (IPCC, 2013). Emissions of nitrous oxide from soils were calculated using IPCC methodology (IPCC, 2006); direct emissions were estimated as 1% of the nitrogen applied to the field as mineral fertiliser, manure and crop residues and indirect emissions were estimated as 1% of nitrogen from volatilisation and 0.75% of leached nitrogen. Factors for yearly emissions of methane from enteric fermentation

for different livestock species and types were taken from Berglund et al. (2009). Since all energy use on the farm, including fertiliser production, was based on biofuel, there were no net carbon dioxide emissions from energy use, but leakage of methane from the biogas chain was included as 0.6% of gas produced when it was used as tractor fuel (Göthe, 2013) and 1% of gas produced when it was used for combined heat and power (Tufvesson et al., 2013). Emissions of nitrous oxide from the production of 'green' mineral nitrogen fertiliser were also accounted for, as 0.80 kg CO₂e per kg of nitrogen produced (Ahlgren et al., undated). Sequestration or loss of carbon in soils was estimated assuming that the soil was in equilibrium in the REF scenario and then calculating the changes in carbon stocks during 30 years (and dividing these emissions/uptake by 30 to give the annual figure) when the crop rotation was changed to those in the different scenarios. For these calculations, the model ICBM was used (Andrén et al., 2004).

Impact on eutrophication and acidification was calculated as eutrophication and acidification potential (EP and AP, respectively) with characterisation factors as in Guinée et al. (2002). As the scenarios show different land uses on the same farm, i.e. in the same location, a more advanced method for assessing the impacts on eutrophication and acidification which takes into account the fate, exposure and damage of emissions would not add any more information in the comparison between scenarios in this case, as what happens to the emissions as they leave the farm would be the same in all scenarios. Emissions of ammonia from manure deposited on pasture and in houses were calculated using emission factors from Berglund et al. (2009). Of the nitrogen in digestate, 4% was assumed to be lost as ammonia to air during storage (Tufvesson et al., 2013) and 15% of the ammonium during spreading (Rodhe et al., 2013). Ecotoxicity was calculated using the USEtox method (Rosenbaum et al., 2008) and data on average pesticide use on crops in Sweden (SS, 2011). For the objectives A Varied Agricultural Landscape and A Rich Diversity of Plant and Animal Life, generally accepted and appropriate qualitative indicators are currently lacking. However, a very important factor for both these objectives is the conservation of semi-natural pasture and agricultural land in general. Hence, in all scenarios analysed, the amount of semi-natural grassland and arable land used was kept constant, and thus the impact on these two environmental quality objectives was roughly the same in all scenarios. Consequently, impacts were not quantified for these two objectives, but they were considered by keeping them constant across scenarios. For more details, see Rööf et al. (2015).

An extensive sensitivity analysis was performed to investigate the robustness of the results including emission factors for nitrous oxide emissions, emissions of methane from enteric fermentation, yield and fertiliser levels, methane leakage from biogas production, ammonia emissions, intensity in the suckler beef production, changes in soil carbon, managing semi-natural grasslands manually or mechanically instead of using animals and raising more animals as steers on pasture rather than bulls indoors.

3. Results

The direct greenhouse gas emissions from animals, fertiliser and energy use were considerably lower (16-41%) for all oat drink scenarios compared with the dairy scenario

(REF) due to less methane emissions from ruminant enteric fermentation (Fig. 2a). Even in scenarios producing the same amount of beef as in the REF scenario (BEEF and BEEF-HP), the direct emissions were 16-24% lower, owing to the lower methane emissions from suckler cows compared with dairy cows and less need for feed. The scenarios with the most spare land (CHICK and PLANT) had somewhat larger emissions of nitrous oxide from soils due to high fertiliser rates applied to the grass-clover crop for biogas production grown on this spare land (Table 1). Hence, the climate impact (not considering the substitution effect from biogas replacing diesel) from the CHICK and PLANT scenarios was in the same range as that from the CHICK-HP and PLANT-HP scenarios, even though more food and protein were produced in the HP scenarios. Arable soils sequestered carbon in the scenarios in which the area of grass-clover cultivation was greater than in the REF scenario (BEEF, CHICK and PLANT), while soils lost carbon in the HP scenarios in which more annual crops were included in the crop rotation (Fig. 1). The substitution effect was largest for the CHICK and PLANT scenarios, which had the most spare land that was used for bioenergy production. The substitution effect together with the carbon sequestration almost cancelled out the direct emissions of methane and nitrous oxide for these scenarios.

The eutrophication potential was similar for all scenarios, since the same amount of land was cultivated in all scenarios, and the eutrophication potential was dominated by nitrate losses, which were similar for all crops (Fig. 2b). Ammonia emissions were larger for those scenarios with more spare land, since more digestate was produced, giving rise to ammonia emissions during storage and spreading. This contributed to acidification potential being 21-37% higher in the BEEF, CHICK and PLANT scenarios compared with the REF scenario (Fig. 2c). Another contributing factor was higher ammonia emissions in houses despite fewer animals, as a consequence of animals being kept in deep litter systems as opposed to slurry systems during the housing period. The ecotoxicity impacts were considerably lower for the BEEF, CHICK and PLANT scenarios compared with the REF scenario and the HP scenarios (Fig. 2d) due to more grass-clover cultivation in the BEEF, CHICK and PLANT scenarios (grass competes well with weeds and is usually not affected by disease or insects and therefore pesticide use is low) and more cultivation of legumes in the other scenarios. It should be noted, however, that the high ecotoxicity result in the REF scenario was a consequence of the set-up of the study; legumes were cultivated as animal feed in the REF scenario to make it comparable to the other scenarios and this protein feed could be provided using other crops.

Fig. 2. a) Climate impact, b), eutrophication potential, c) acidification potential and d) ecotoxicity impacts of a fictitious dairy farm producing 880 tonnes of milk and 20 tonnes of bone-free beef per year (REF) and of six alternative scenarios in which the milk production was replaced by oat drink production and the production of beef by suckler beef (BEEF), chicken (CHICK) or plant-based protein (PLANT). In all scenarios, 49 ha of semi-natural grassland were grazed. HP denotes that the total amount of protein supplied in the scenarios was the same as in the REF scenario.

4. Sensitivity analysis

This study used the IPCC emissions factor of 1% for direct nitrous oxide emissions from soil for all crops and from manure on pastures. However, Regina et al. (2013) found that nitrous oxide emissions in grass-clover cultivation were significantly lower than from soils producing annual crops. Therefore the sensitivity analysis tested how a considerably higher emissions factor for annual crops (3%) compared with grass-clover (0.3%) affected the outcome. With this 10-fold difference in the emissions factor for grass-clover compared with annual crops, the climate impact of the BEEF-HP scenarios was slightly higher than that of the REF scenario, while all other oat drink scenarios still had a lower climate impact than the REF scenario.

Methane emissions from enteric fermentation are also associated with great uncertainties. However, even when the emissions factor for dairy cows was reduced by 20% from 135 kg to 108 kg CH₄ per cow and year and the corresponding factor for suckler cows was simultaneously increased by 20% from 77 to 92 kg, the ranking between scenarios did not change. There was still a lower climate impact from producing oat drink and beef using suckler herds than producing milk and beef jointly in a dairy production system.

The results were not sensitive to the yield levels of crops or to the parameters used to calculate energy use and nitrous oxide emissions from the production of green mineral nitrogen fertiliser. The sensitivity analysis tested how the results were affected if the grass-clover crop was not fertilised with nitrogen, as it is possible to obtain high yields based on nitrogen from legume nitrogen fixation only. The results showed that the climate impact for all scenarios decreased by 10-20% but the reduction was greater in the oat drink scenarios than the dairy REF scenario, hence reinforcing the result of lower climate impact in the oat producing scenarios.

The results were sensitive to assumed methane losses from the biogas chain. When this loss was assumed to be 4% (instead of 0.6%) when it was used for fuel and 2.5% (instead of 1%) when it was used for heat and power generation, corresponding to current installed capacity (Göthe, 2013; Tufvesson et al., 2013), the climate impact increased by 6-29% for all scenarios. The increase was greatest for the CHICK and PLANT scenarios, which had a lot of spare land and hence most production of biogas. However, the overall ranking of the scenarios did not change; the REF scenario still had the highest climate impact.

Higher ammonia emissions from storage and spreading of the larger amount of digestate in the BEEF, CHICK and PLANT scenarios caused the acidification potential of these scenarios to be higher than in the REF scenario. There are several known technical mitigation options for these emission sources, as well as emissions from manure in animal houses. However, even when ammonia emissions from manure deposited on pastures and in houses were assumed to decrease by 50% and ammonia emissions from storage and spreading of digestate by 75%, the acidification potential of the BEEF, CHICK, PLANT and BEEF-HP scenarios was still higher than in the REF scenario.

The beef production system using suckler herds modelled in this study used average Swedish data. However, it is known from previous studies that the climate impact of beef production systems is highly sensitive to the intensity, as slower growth rates and therefore higher slaughter age result in more methane emissions from enteric fermentation per kg of meat produced (Röös et al., 2013). A considerably more extensive suckler beef system was therefore modelled, assuming that all offspring were slaughtered at an age of 36 months (instead of 15 for bulls, 18 for steers and 22 for heifers) and that all male offspring were castrated, so they could graze outdoors. The climate impact of the BEEF scenarios (in which the yearly production of beef was equivalent to that in the REF scenario) was then as high as the climate impact of the REF scenario. Hence, using very extensive beef suckler systems to provide beef in equivalent amounts to that produced in dairy systems does not provide a climate advantage. However, for the other scenarios in which the number of cattle needed on the farm was determined by the grazing services needed to preserve the 49 ha of semi-natural grassland, the total climate impact of the farm decreased with lower intensity ruminant production, since all male offspring then grazed and fewer animals in total were needed. The consequence of this was also that less beef was produced and more chicken in the CHICK scenario and more plant-based protein in the PLANT scenario.

Estimating changes in soil carbon is difficult and associated with considerable uncertainties. The results depend on the initial carbon content in the soil and other soil characteristics, as well as climate features such as temperature and precipitation (Andrén et al., 2004). When calculating arable soil changes in this study, it was assumed that the soils in the REF scenario were in equilibrium and changes in the arable soils were calculated with the REF scenario soil carbon content as a starting point. However, when a higher carbon concentration was assumed as a starting point (2.3%), all the HP scenarios and the REF scenario lost considerably more carbon, and sequestration rates in the BEEF, CHICK and PLANT scenarios were reduced to very low levels. Nevertheless, the ranking between scenarios was not affected, although the difference between the REF scenarios and the other scenarios decreased by a few percentage points.

One of the starting conditions in this study was the use of ruminants in the preservation of semi-natural grassland. Hence, in all scenarios 49 ha of grassland were grazed. However, these pastures could be managed using other grazing animals, e.g. horses, and some areas would benefit from manual or mechanical management rather than grazing (Carlsson et al., 2014). The sensitivity analysis tested how the removal of all animals from the farm affected the results. Since no meat was then produced, 35 tonnes of protein needed to be produced through 880 tonnes of oat drink, 105 tonnes of cereals and 81 tonnes of legumes. It was assumed that the fuel needed to harvest and remove the biomass from the pastures corresponded to 105 litres of diesel per ha (Daniel Nilsson, Swedish University of Agricultural Sciences, pers. comm.). The biomass removed was used to produce additional biogas. The direct emissions decreased by 61% compared with the REF scenarios and the substitution effect from biogas replacing diesel more than compensated for these emissions (Fig. 3).

For all scenarios, it was assumed that 80% of male offspring were raised as bulls and hence did not graze semi-natural grassland, corresponding to current levels (Taurus, 2014). However, if more of the male offspring were raised as steers, more grazing services would be delivered by the animals and fewer animals in total would be needed to graze the 49 ha of pasture on the farm. Hence, the sensitivity analysis tested how raising all male offspring as steers in the REF scenario would affect the results. Sixty-four dairy cows (183 animals in total) sufficed to manage the pastures. Milk production was reduced to 563 tonnes ECM and therefore 317 tonnes of oat drink were also produced in order to reach a total milk/oat drink production of 880 tonnes. Beef production decreased from 20 to 13 tonnes, and therefore 37 tonnes of cereals and 29 tonnes of legumes were produced to achieve total protein production of 35 tonnes (equivalent to total protein in the REF scenario including that in milk and meat). The climate impact for this farm producing both milk and oat drink was in the same range as for the BEEF scenario, i.e. approximately 20% less than the REF scenario (Fig. 3). Hence, if all dairy offspring are used to provide the grazing services needed (grazing of 49 ha), the number of dairy cows on the farm can be reduced by 36% (and milk production will decrease correspondingly).

Fig. 3. Climate impact of a fictitious dairy farm producing 880 tonnes of milk and 20 tonnes of bone-free beef per year (REF), the same farm when all dairy cow offspring were used for grazing (compared with only 20% of male offspring in REF), which reduced the total number of animals needed on the farm to manage semi-natural grassland (REF INCR PASTURE-HP), and the same farm when all animal production was replaced with production of plant-based protein (NO ANIMALS-HP). For all three alternatives, the same amount of protein for human consumption and feed was produced in total and 49 ha of semi-natural grassland were grazed.

5. Discussion

Life cycle assessment studies and other system level studies of complex systems can be designed in very many different ways and hence answer different types of questions (Börjeson et al., 2006). This study fits into neither the traditional accounting nor the consequential field of life cycle assessment studies (Ekvall & Weidema, 2004; Zamagni et al., 2012). Rather, it contains explorative scenarios in which dairy production on a farm is replaced by oat drink production and quantifies the environmental impacts that are a consequence of the inherent properties of these systems, i.e. the dairy farm is inevitably associated with methane emissions from the ruminants and will require more land for feed production. The decision to make the farm self-sufficient in energy was motivated by minimising the influence of future very uncertain energy production and markets on the results. (In this study the (small) farm produced fuel, fertiliser, heat and power, which is inefficient use of capital goods and, if implemented in real life, the production of these should preferably be concentrated to a few larger units.)

Hence, this study devised and evaluated a low climate impact agricultural system that delivers the services demanded by society; milk or a drink that can function as milk, beef, meat or protein depending on the perceived need for this, and grazing services for biodiversity conservation. The results show that it is possible to produce all these products and services with a considerably lower climate impact by producing oat drink instead of milk. How much lower the climate impact can potentially be depends on whether all beef from the dairy system needs to be replaced by beef from suckler herds. If some of it can be replaced with chicken or plant-based protein and the substitution effect of replacing diesel with biogas is valid (i.e. there is diesel in society to be replaced, replacement is on a 1:1 basis etc.), the climate impact could be 80% lower, or even 90% lower if soil carbon changes are also included. Hence, there is great potential for reducing greenhouse gas emissions through the production of oat drink instead of cow's milk with preserved grassland for biodiversity conservation. The climate benefit is even greater if the opportunity cost of using land is included in the analysis and bioenergy is produced on land that is freed from producing oat drink instead of milk. Importantly, however, for this to happen, incentives to manage semi-natural grassland have to be introduced, as such management does not follow as an inherent property of oat drink production. In addition, consumers must be incentivised to consume oat drink instead of cow's milk and, if they also replace some of their beef consumption with consumption of chicken or cereals and legumes, the climate impacts can be substantially lower.

The bioenergy production on spare land in this study led to increased nitrogen pollution, a known possible goal conflict in bioenergy production (Erisman et al., 2010; van der Voet et al., 2010). However, the production of biogas from a grass-clover crop on all spare land was a choice in the set-up of this study and the spare land could be used for other purposes, such as some other type of bioenergy production with less potential nitrogen losses, establishment of wetlands or more extensive cultivation on the cropland actually needed, which could potentially reduce the acidification and eutrophication impacts substantially (Vohla et al., 2011).

However, what needs to be carefully considered in a transition to more plant-based eating and farming is the need for a sound crop rotation not only containing annual crops, but also incorporating a grass-clover crop or another perennial crop with similar characteristics, to prevent the accumulation of weeds and to maintain or build soil carbon stocks and soil structure (Taylor et al., 2006). If no or few animals are present on the farm to utilise this grass biomass, it is crucial to handle it in such a way that it does not increase nutrient pollution. For Sweden, a country with a cold climate, the keeping of grazing animals in semi-natural grassland during the mild period of the year introduces the need to grow forage for winter feed on arable land and therefore contributes to a more mixed farming system if the rearing of animals is not concentrated to only a few places. All scenarios in this study included more than 40% grass-clover in the crop rotation, which is considered a sufficient level in most circumstances.

This study was performed in the context of Sweden but the results are valid for many other areas around Europe with similar production conditions and systems and similar consumption habits. There are also circumstances in which results are not applicable. For example, in areas where the agricultural land consists of only non-croppable pasture land and no cropland (requiring a climate that enables grazing outside all year round or import of winter feed), the production of plant-based drinks is not possible at all and the only way to produce food from these areas would be using ruminants to produce milk and meat. However, the trend in dairy production globally is towards intensified large-scale systems using concentrates in addition to roughage in the diet (Beldman et al., 2010). In such systems, considering the opportunity cost of using cereals as feed instead of for direct human consumption (as with oat drink) is always relevant.

It is important to note that the results from this study cannot be interpreted as meaning that replacing consumption of 1 kg of milk with 1 kg of oat drink *in isolation and in itself* will decrease the climate impact to the levels presented here *and* deliver grazing services and bioenergy production on spare land, as these are not inherently coupled to oat drink production. Dalgaard et al. (2014) calculated the climate impact of 1 kg of Swedish milk using consequential modelling, which included activities in the product system “to the extent that they are expected to change as a consequence of a change in demand for the functional unit” (Sonnemann & Vigon, 2011), hence establishing a cause-effect chain of such a change and studying the consequences of this. In the study by Dalgaard et al. (2014), substitution was used to divide the climate impact from the dairy systems between the milk and the beef. Brazilian beef was identified as the marginal beef (Brazil was the country exporting beef to the EU with the highest annual increase in beef production), i.e. it was assumed that a change in the demand for milk would lead to a change in production of Brazilian beef. Hence, a decrease in demand for Swedish milk could result in an increase in production of Brazilian meat to replace the beef no longer produced in the Swedish dairy production system. As Brazilian beef production is very extensive and the climate impact from Brazilian beef is high (Cederberg et al., 2009b), the climate benefit from decreased consumption of Swedish milk is partly cancelled out. The work by Dalgaard et al. (2014) is an example of a predictive study in

which (global-level) marginal changes in demand are considered under the assumption that current trends in demand and production will continue. Such studies provide valuable input on probable short-term responses to isolated changes in demand, but predictive studies are not useful for exploring more long-term targets which match e.g. formulated environmental goals (Börjeson et al., 2006). For such purposes, explorative or normative scenarios are needed in which larger-scale changes are possible. This study analysed examples of such scenarios.

An expected objection to this study is likely to be that oat drink is not milk. Whether and to what extent oat drink or other plant-based milk alternatives are a substitute for cow's milk in nutritional terms depends to a large extent on what the rest of the diet comprises. For example, if milk is the major source of calcium and protein for an individual, turning completely to unfortified plant-based drinks might result in serious malnutrition for that individual. On the extreme end, there are reported cases of protein deficiency in the developed world from infants consuming rice drink (Mäkinen et al., 2015). On the other hand, as protein consumption is generally high in the developed world (Westhoek et al., 2011) and since many plant-based alternatives are fortified with critical nutrients, a large part of the population could replace cow's milk with plant-based drinks without any negative health implications. Hence, whether milk can be replaced by plant-based alternatives is highly context-specific.

6. Conclusions

This study demonstrated great potential for lowering the climate impact by producing oat drink instead of cow's milk on a Swedish farm, while still preserving grazing services for biodiversity conservation. It also revealed potential to reduce the acidification and eutrophication potential and ecotoxicity impacts by producing oat drink instead of dairy milk, though these environmental impact categories are more sensitive to the use of the land freed up after the oat drink and other replacement products have been produced. Further positive climate effects could be achieved if the bioenergy produced on freed land replaces fossil energy.

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