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Research article

A large share of climate impacts of beef and dairy can be attributed to ecosystem services other than food production

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ABSTRACT

Domesticated ruminants supply nutrient-dense foods but at a large environmental cost. However, many ruminant production systems are multi-functional, providing ecosystem services (ES) other than direct provision of food. When quantifying the climate impact of ruminant products using life cycle assessment (LCA), provisioning ES (i.e. beef and milk) are generally considered the only valuable outputs and other ES provided are ignored, which risks overlooking positive contributions associated with ruminant production. Non-provisioning ES can be included in LCA by economic allocation, using compensatory payments (through agri-environmental schemes) as a proxy for the economic value of ES. For example, farmers can receive payments for maintenance of pastures, which supports e.g. pollination. However, the association between different payment schemes, the ES provided, and livestock production is not always straightforward and it can be difficult to determine which payment schemes to include in the allocation. This study examined how accounting for ES in quantification of climate impact for beef and milk production on Swedish farms was affected by different ways of coupling ES to livestock production through payment schemes. Quantification was done using LCA, attributing the climate impact to beef, milk, and other ES by economic allocation. This resulted in <1–48% and 11–31% of climate impacts being allocated to other ES, instead of beef and milk, respectively, affecting suckler farms most. The results were influenced by which payment schemes, representing different ES, that were included; when only payments directly related to livestock rearing were included, the difference in the climate impact was still large between farm types, while the difference decreased considerably when all environmental schemes were included. While emissions do not disappear, ES-corrected climate impact can potentially be useful as part of consumer communication or in decision-making, reducing the risk of overlooking ES provided by ruminant production in a simpler way than using separate indicators.

Author contributions

Karin von Greyerz: Conceptualization, Methodology, Formal analysis, Writing – original draft, Visualization. **Pernilla Tidåker**: Conceptualization, Methodology, Writing – review & editing. **Johan O. Karlsson**: Conceptualization, Methodology, Writing – review & editing. **Elin Röös**: Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration, Funding acquisition.

1. Introduction

Food production has profound effects on ecosystems and causes major negative environmental impacts, including contributing to climate change. The agriculture sector produces an estimated 11% of anthropogenic greenhouse gas (GHG) emissions in the European Union (EU), making it the second most emissions-intense sector (European Environment Agency, 2021). Livestock production causes 81% of agricultural GHG emissions and uses approximately 65% of total agricultural land in the EU (Leip et al., 2015). Ruminants are among the livestock sector's greatest contributors to global warming, generating emissions from enteric fermentation, feed production, manure management, energy use in barns, and deforestation (Gerber et al., 2013).

However, ruminants provide nutrient-dense foods, and ruminant systems are multi-functional to varying degrees, generating other values to society (Food and Agriculture Organization of the United Nations, 2016a; 2016b). A key concept for describing such contributions is *ecosystem services* (ES), defined by the Millennium Ecosystem Assessment (2005) as *"benefits people obtain from ecosystems"* and divided into

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provisioning (i.e. production of food and other materials), regulating, cultural, and supporting ES. Many ES are now in rapid decline, requiring urgent and concerted actions to reverse this trend (IPBES, 2019). Ruminants can contribute to ES in several ways. Grasslands used to provide feed for ruminants are associated with *e.g.*, carbon storage, recreational values, and biodiversity contributing to e.g., pollination (Bengtsson et al., 2019; Zhao et al., 2020). In Sweden, ruminants are indispensable in maintenance of semi-natural pastures that are not cultivated or fertilized, other than directly by grazing animals, as these endangered ecosystems host many red-listed species (Eriksson and Cousins, 2014). However, ruminant production systems vary from intensive systems with high yields obtained using high proportions of concentrates for feed, low slaughter age, and specialized indoor production, to more extensive systems based on grazing with higher slaughter age and lower milk yields (Capper, 2012; Kiefer et al., 2015; Vagnoni et al., 2015; Ogino et al., 2016). Hence, the extent to which different livestock systems contribute to ES provisioning varies widely.

The environmental impact of ruminant production is commonly assessed using life cycle assessment (LCA) (de Vries et al., 2015; Baldini et al., 2017; Clune et al., 2017), which evaluates environmental impacts of products and services from all processes throughout the entire life cycle (SIS, 2006). LCA of milk and beef (in this study meaning beef from all cattle, including from culled dairy cows) considering the impact category of climate change (hereafter called climate impact) show results in the range 0.54–7.5 kg carbon dioxide equivalents (CO_2e) per kg milk and 11–110 kg CO_2e per kg bone-free beef globally (Clune et al., 2017). In the EU, where ruminant production is commonly more intensive, climate impacts are in the lower range; 17–42 kg CO_2e per kg bone-free meat and 1–2.3 kg CO_2e per kg milk (Lesschen et al., 2011). Still, these impacts are considerably higher than for most other comparable food products, due to high methane (CH_4) emissions and low feed efficiency. However, LCA for ruminant systems commonly include only beef and milk as valuable outputs, and not other ES potentially provided (de Vries et al., 2015; Baldini et al., 2017; Clune et al., 2017). This risks overlooking positive contributions to ES, other than direct food provisioning, when making decisions about future livestock systems. When non-provisioning ES are ignored in LCA, meat produced in intensive systems generally has lower climate impacts than meat from extensive systems (Ogino et al., 2016; Bragaglio et al., 2018). Some LCA studies have attempted to consider the multi-functionality in animal production systems using economic allocation, where the environmental impact is distributed proportionally to outputs (foods and other ES) based on their economic value (Ripoll-Bosch et al., 2013; Kiefer et al., 2015; Bragaglio et al., 2020). However, while food products can be valued using market prices, attributing value to other ES is less straightforward. To assign a monetary value to ES, previous studies have used payments through agri-environmental schemes, representing the value society assigns to certain ES. Ripoll-Bosch et al. (2013) used this method for considering cultural ES in three representative lamb production systems and found 0–46% lower climate impact for meat when ES were considered, shifting emissions from meat to other ES provided. Kiefer et al. (2015) used the same allocation method when assessing the climate impact of German milk production, considering preservation and upkeep of cultivated landscapes and preservation of endangered breeds. Payments for *e.g.* organic farming and management of biodiverse grassland and the price of milk was used to allocate emissions between the meat, milk and other ES. This economic allocation led to 1–29% of emissions being allocated to non-provisioning ES. Bragaglio et al. (2020) calculated the climate impact of beef considering biodiversity in terms of keeping local breeds and grazing on natural grasslands, conservation of landscapes, and socio-economic viability of rural areas on 25 farms in Italy divided into four clusters based on production system. That study found that accounting for ES with economic allocation shifted 0–43% of emissions from beef to other ES, i.e. milk for dairy farms and non-provisioning services e.g. services related to biodiversity conservation and cultural services.

A multitude of environmental payments schemes are available for farmers that are more or less directly associated with the delivery of ES, including support to organic farming and farming in areas of natural constraints (ANC) (farming in areas where agricultural production is more challenging due to unfavorable natural conditions). There are also a range of payment schemes more directly connected to livestock, including support for biodiversity conservation in semi-natural pastures or preservation of local livestock breeds. It can therefore be difficult to decide which payment scheme/s to include when using these as a base for economic allocation in LCA to account for non-provisioning ES, especially as payments are sometimes only vaguely reflecting the ES provided (Simoncini et al., 2019), which can give variable results.

Therefore, the aim of this study was to examine how the climate impact of beef and milk from Swedish farms representing different production systems was affected by different ways of coupling non-provisioning ES to livestock production through payment schemes. Hence, this study adds to the current literature on using economic allocation to include ES as an output in LCA by considering varying ways of including payment schemes. Quantification of the climate impact was performed using LCA for 10 Swedish cattle farms with different management practices to represent a breath in production systems while capturing the specificity provided by studying real farms. Risks and opportunities with using ES-corrected climate impact values for beef and milk in different applications were also discussed.

2. Material and method

2.1. Case study farms

Cattle production in Sweden varies from intensive dairy production with intensive breeding of dairy calves to extensive suckler production. Animal welfare regulations require outdoor grazing for all cattle except bulls, in grazing periods lasting up to 270 days, but housing periods are often long because of the harsh climate and intensive rearing. Grazing is based on leys and semi-natural pastures. Silage, cereals, and concentrates are commonly used as additional feedstuffs, with feed use differing between farms. The main feedstuff is silage harvested from grass-clover leys grown on cropland, often in rotation with other crops.

This study assessed 10 Swedish cattle farms with different production systems: Two specialist dairy farms selling surplus calves to other farms, seven pure beef-producing farms (with suckler herds and/or bought in calves), and one farm producing milk and also fattening calves for beef. The farms were all part of the Swedish case study of the Uniseco project (https://uniseco-project.eu/) and selected purposively to represent varying cattle production systems throughout Sweden. Hence, the farms represented the five production systems described below. The farms differed in terms of e.g. geographical location, feed, amounts of beef and/or milk produced, and bovine density, which are summarized in Table 1.

1. *Suckler systems*

Four farms breed calves from a herd of suckler cows, and one of these also fattens bought-in suckler calves. Most feed is produced on-farm and consists of forages and some cereals. These farms will be referred to as Suckler A, B, C and D.

2. *Dairy calf systems*

Two farms fatten dairy calves bought from neighboring dairy farms. The feed consists of forage and cereals grown on-farm and bought-in concentrates. These farms will be referred to as Dairy calves A and B.

3. *Suckler and dairy calf system*

One farm breeds suckler calves and fattens calves from other dairy

Table 1
Characteristics of the 10 Swedish farms assessed.

	Suckler A	Suckler B	Suckler C	Suckler D	Suckler and dairy calves A	Dairy calves A	Dairy calves B	Dairy and dairy calves A	Dairy A	Dairy B
Area of natural constraints	No	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Organic/conventional farming	Organic	Organic	Organic	Organic	Organic	Conventional	Conventional	Organic	Organic	Organic
<u>Farm area</u>										
Cropland (ha)	27	27	59	51	110	48	520	150	204	80
Pastures with general values[a] (ha)	6	25	6	16	4			7	40	12
Pasture with specific values[a] (ha)	3.5		14	22	34				52	19
<u>Bovine production</u>										
Breed	Beef	Beef	Native[b]	Beef	Beef and dairy	Dairy	Dairy	Native[b]	Dairy	Dairy
Bovine density[c] (AU/ha)	0.65	0.45	0.21	0.72	0.42	0.63	0.84	0.36	0.60	0.78
Milk production[d] (t FPCM/y)								110	1400	550
Beef production[e] (t CW/y)	3.2	3.8	57	12	14	7.6	6000	6.3	20	6.2
<u>Feed</u>										
Forage (% of diet in DM)[f]	46	26	30	51	43	46	34	64	55	36
Cereals (% of diet in DM)[f]			<1		<1				11	22
Concentrates (% of diet in DM)[f]						<1	66	6	10	13
Other feed (% of diet in DM)[f]		<1				5			5	
Grazing on cropland (% of diet in DM)[f]						48				18
Grazing of semi-natural pastures (% of diet in DM)[f]	54	74	70	49	56			30	20	11
Bought-in feed (% of diet in DM)[f]				4		6	66	6	13	14
Grazing period (days)	200	270	Heifers: 180 Others: 270	180	Suckler cows: 270 Others: 180	180		125	Heifers: 180 Dairy cows: 135	Calves: 150 Heifers: 180 Dairy cows: 270
<u>Manure management system</u>										
Deep bedding with no mixing (%)	5	100	90	100	40	100	17	100	9	5
Solid storage (%)			10		20		38			
Liquid with natural crust cover (%)	95				40		45		91	95

[a] In Sweden, payments are given to semi-natural pastures based on a classification into 'general values' or 'specific biological and cultural values'.
[b] Endangered domestic animal breed.
[c] Animal unit (AU) per hectare.
[d] Ton fat and protein corrected milk (FPCM) per year.
[e] Ton carcass weight (CW) per year.
[f] Percent of diet in dry matter (DM).

farms. The feed consists mostly of forage produced on-farm. This farm will be referred to as Suckler and dairy calves A.

4. *Dairy systems*

Two farms specialize in milk, but also produce some beef from culled dairy cows. The calves not used as replacement heifers are sold to other farms for fattening. The feed consists of forages, cereals, and other feed crops produced on-farm, plus concentrates. These farms will be referred to as Dairy A and B.

5. *Dairy and dairy calves system*

One farm, in addition to producing milk and beef from culled cows, also fattens calves not used as replacement heifers. The feed mostly consists of forages grown on-farm and some concentrates. This farm will be referred to as Dairy and dairy calves A.

Only total yearly feed consumption on-farm was known, so feed intake per animal was estimated based on gross energy (GE) requirements in animals, GE content in feed, and farmer-estimated total feed consumption (von Greyerz, 2021). Data on GE content in feed came from IPCC (2019b). GE requirements were calculated using IPCC (2019b) tier 2 separately for calves, replacement heifers, dairy cows, dry cows, breeding bulls, suckler cows, heifers for meat, and steers for meat, including requirements for maintenance, growth, activity, lactation, and pregnancy. The calculations were based on body weight, mature weight, weight gain, amount of milk produced, fat content in milk, and fraction of digestible energy in feed, using farm-specific parameters. When fat content in milk was unknown (for suckler cows), it was set to that in fat- and protein-corrected milk (FPCM), *i.e.*, 4% fat and 3.3% protein (International Dairy Federation, 2015) and with amount of milk produced according to Swedish Environmental Protection Agency (2019). Constants for maintenance energy, activity energy, and energy for growth were set according to IPCC (2019b), considering farm and bovine characteristics. Feed digestibility was calculated from reported amount of digestible energy in feeds (Swedish University of Agricultural Sciences, n.d). During the grazing period, dairy cows were assumed to consume 50% of their forage from grazing, based on Spörndly and Kumm (2010), while other cattle did not consume any other feed. Concentrate and cereal fraction in total feed intake was assumed to be similar for all animals on the farm, except for dry cows that were assumed to only eat forage, unless otherwise stated by the farmer (SM, Table S1). Forage fraction was then adjusted to match the required feed intake, considering the animal's energy needs. Feeding losses were assumed to be 3% for all animals except dairy cows, for which losses of 10% and 5% for forages and concentrates, respectively, were assumed, following Hessle et al. (2017).

Since herds can differ between years, *e.g.*, if the farm buys (or slaughters) more animals, a herd in equilibrium typical of each farm was used to calculate the carbon footprint, following von Greyerz (2021). The number of suckler cows and dairy cows were therefore held constant. The replacement rate was 20% for suckler cows (Cederberg, 2009), unless otherwise stated by the farmer (SM, Table S1), while for dairy cows the replacement rate was set to the number of cows slaughtered (reported by the farmer). The number of replacement heifers was set to equal the number of cows replaced. Each cow was assumed to give birth to one calf per year, unless otherwise stated by the farmer (SM, Table S1). Calf mortality and number of calves bought in were both set to the number reported by the farmer. The climate impact of bought-in dairy calves was based on calf weight and climate impact per kg dairy calf weight (Moberg et al., 2019). The climate impact of bought-in suckler calves was set to the impact from one suckler calf in one year and the impact of the growing calf based on calf age when bought in, with impacts taken from Moberg et al. (2019). No allocation to non-provisioning ES was made for these impacts, which might underestimate the effect of the allocation method for farms buying calves, depending on the calves' and the mother animals' contribution to ES and impact. Steer:heifer ratio for beef animals was set to that reported by the farmer for the study year, as was the mortality rate. When live-weight (LW) or carcass-weight (CW) was not stated by the farmer, the LW:CW ratio was set to 1:0.5, based on Strid et al. (2014).

2.2. System boundaries and functional unit

The functional unit (FU), *i.e.*, the quantitative reference unit for the system functions, chosen was 1 kg carcass weight (CW) for beef and 1 kg

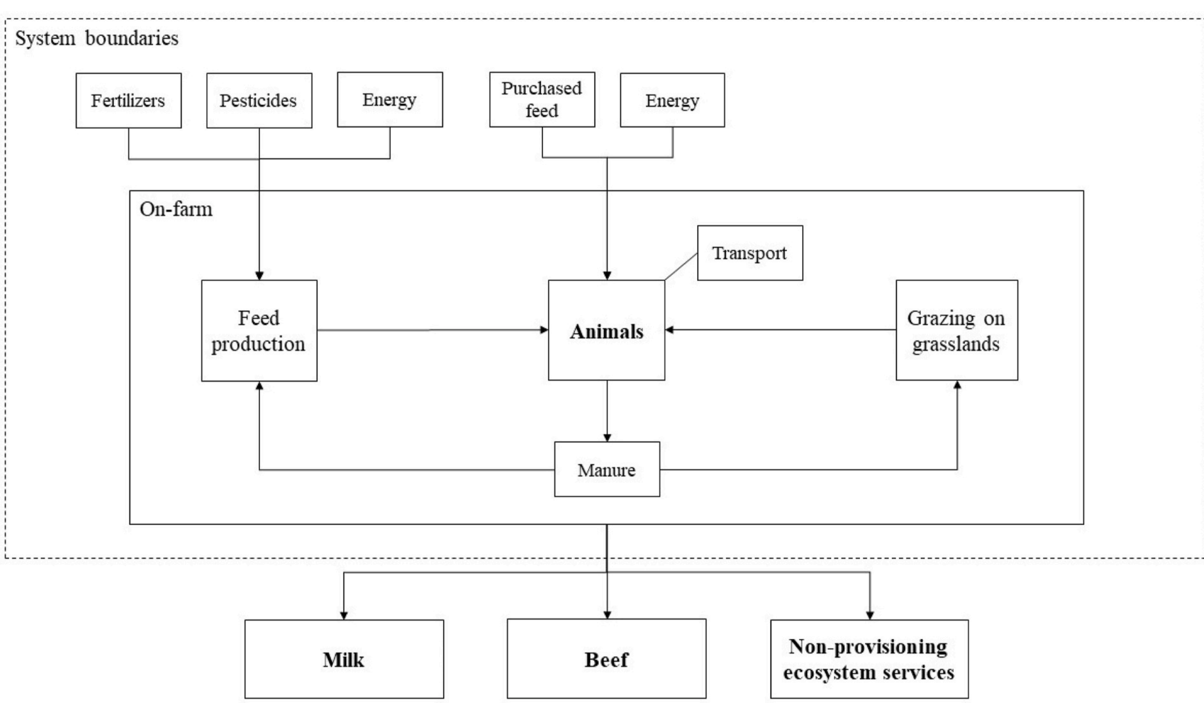

Fig. 1. System boundaries with inputs, outputs, and emission sources included in the analysis.

FPCM for milk. Processes from “cradle-to-gate”, *i.e.,* until animals and milk leave the farm, were included in the system boundaries (Fig. 1). Emissions considered were: CH_4 from enteric fermentation, CH_4 and nitrous oxide (N_2O) from manure management, N_2O from grazing land due to manure deposited by grazing animals, and carbon dioxide (CO_2), CH_4, and N_2O from feed production, transport, on-farm energy use and purchased products. Emissions and sequestration of CO_2 from soil carbon stock changes caused by feed production were included for feed produced on-farm and for purchased feed. For feed produced on-farm, emissions associated with land use change were excluded, since the farms had not altered land use management substantially in the previous 20 years (IPCC, 2019a). For purchased feed, land use change was included for soy produced outside of Europe. For feeds produced in Europe, land use changes was excluded (Pendrill et al., 2020). Processes post-farm gate, *i.e.*, slaughter, processing, packaging, and transport, were assumed to be similar for all systems and therefore not included in the system boundaries. Capital goods were also excluded since it has been shown that these make minor contributions to climate impacts for agricultural products (Frischknecht et al., 2007).

2.3. Climate impact

The environmental impact category considered was climate impact, using CO_2e. For conversion to CO_2e, global warming potential in a 100-year perspective (GWP_{100}) with climate-carbon feedbacks (1 for CO_2, 34 for CH_4, 298 for N_2O), was used (IPCC, 2013). For more details on these calculations, see von Greyerz (2021) and supplementary materials. When assessing the environmental performance of different livestock systems it is important to consider a wide range of impact categories (van der Werf et al., 2020) to allow for a fair comparison and avoid pollution swapping. However, since the aim here was to study the influence of the allocation method, only one impact category was included since the allocation factors would be the same for all impact categories and therefore also the relative change of the impact.

Emissions of CH_4 from enteric fermentation were quantified with the tier 2 approach from IPCC (2019b) (SM, Table S2) from GE intake and a CH_4 conversion factor (Y_m) set to 6.3%, based on fraction of digestible energy in feed according to IPCC (2019b).

Emissions of CH_4 from manure management were quantified with the tier 2 approach from IPCC (2019b) (SM, Table S2) from volatile solids excreted by livestock and factors for the maximum CH_4-producing capacity and CH_4 conversion of manure taken from IPCC (2019b). Amount of volatile solids excreted was estimated from GE, ash fraction in feed, urine energy fraction in GE, and digestible energy fraction in feed, where ash fraction in feed was approximated with feed estimations and ash content from Swedish University of Agricultural Sciences (n.d), and urine energy fraction was based on IPCC (2019b).

Emissions of N_2O from manure management were quantified with the tier 2 approach from IPCC, (2019b) (SM, Table S2), using nitrogen (N) excretion from bovines calculated with IPCC, (2019b) tier 1 values, including direct and indirect emissions, the latter caused by N volatilization primarily as ammonia and nitrogen oxides and leaching. N excretion was estimated with IPCC (2019b) tier 1 from N intake and N retained in the animal, calculated using GE, protein fraction in feed, weight gain, and net energy for growth. Protein fraction in feed was calculated from feed estimations and protein contents from Swedish University of Agricultural Sciences (n.d).

Soils used for crop production generate direct and indirect emissions of N_2O (SM, Table S2), the latter caused by N volatilization primarily as ammonia and nitrogen oxides and leaching, from N added with fertilizer, manure, and crop residues. These emissions were calculated with the tier 2 approach from IPCC (2019c) from amount of added N, emissions factors for different amendments in wet climates from IPCC (2019c), and fractions of N volatilized and leached from IPCC (2019c), following the Swedish national inventory report 2019 (Swedish Environmental Protection Agency, 2019). Emissions from organic soils were not considered and all soils were treated as mineral soils. Nitrogen added with crop residues was calculated according to IPCC (2019c) tier 1, from yield, fraction of residues left in the field, and proportion of crops renewed annually, using values of above-ground residues:yield ratio, root-biomass:shoot-biomass ratio, and N content in residues from Andrist Rangel et al. (2016) and IPCC (2019c), also following the Swedish national inventory report 2019 (Swedish Environmental Protection Agency, 2019). Nitrogen added with synthetic fertilizers was calculated from N content in fertilizers and fertilizer use reported by farmers. Nitrogen from organic amendments and manure was calculated based on amounts reported by farmers and N content in similar amendments reported by Cool Farm Alliance (2019). Pastures also generate N_2O emissions when grazed, from manure deposited by grazing animals. Amount of N added to pastures with manure was estimated based on fraction of grazing period spent outside, estimated N excretion, and grazing period length reported by farmers. For farms where animals have outdoor access year-round, the manure was assumed to be collected and stored during winter (approximated as three months). For dairy cows, the fraction of the day spent outside was set to 70% (Wredle et al., n.d) when unknown. Nitrogen added to soils by grazing animals was calculated from estimated dry matter (DM) intake from grazing.

Emissions of GHG from energy use in barns and from feed production were calculated using emission factors for different energy sources from Gode et al. (2011). Emissions from transport were approximated following Kannan et al. (2016), based on vehicle and trailer weight, fuel consumption, and total weight of transported animals, choosing vehicle and trailer sizes similar to those on-farm.

Soil carbon stock changes were estimated for cropland using the Introductory Carbon Balance Model (ICBM) (Andrén et al., 2004), which estimates soil organic carbon content in topsoil on a yearly basis using initial soil carbon content and annual carbon input. A more detailed description is given in supplementary materials.

2.4. Valuable outputs and allocation

Valuable outputs considered were sold beef, milk and calves as well as non-provisioning ES. Cattle also generate manure, but since it was exclusively used in production of feed on-farm, and therefore did not leave the system, it was not considered an output. To distribute the climate impact between all outputs considered, economic allocation was used. Economic allocation excluding non-provisioning ES, *i.e.,* only considering beef, calves, and milk, was performed for comparison. For sold beef and milk, the economic value was calculated from amount sold and conventional producer prices in Sweden (2016) for both conventional and organic farms (Table 2). The reason why allocation between non-provisioning ES and food (milk/beef) was based on the conventional price, also for the organic farmers selling their products with a premium price, was that we considered the conventional price to best

Table 2
Producer prices for milk and bovines in Sweden (2016), used for allocation. Values converted from Swedish krona (SEK) to Euro (EUR) with conversion rate 10:1.

	Average price
Milk[a] (EUR/kg)	0.31
Cattle sold to other farms[b] (EUR/kg LW)	Calves: 2.8
	Heifers: 2.3
Cattle sold to slaughter[c] (EUR/kg CW)	Culled cows: 4.0
	Young bulls: 4.3
	Heifers: 4.2
	Steer: 4.3

[a] Euro (EUR) per kg from Swedish Board of Agriculture, (n.d.a).
[b] EUR per kg live weight (LW) estimated from average for dairy breed from HKScan (n.d.).
[c] EUR per kg carcass weight (CW) estimated from average for class R3 for bulls and O3 for others from Swedish Board of Agriculture (n.d.b).

Table 3
Payments through the Swedish rural development program (2020 values) (Swedish Board of Agriculture, 2020) used for valuing ecosystem services in this study.

Payment	Description	Value
Maintenance of semi-natural pastures[a)]	Grazing of semi-natural grasslands	General value: 100 EUR/ha Specific values: 280 EUR/ha
Keeping of endangered domestic animal breeds[b)]	Breeding of endangered domestic animal breeds	145 EUR/AU
Farming on areas of natural constraints, ANC[c)]	Farming on areas with natural constraints, for pastures with specific values and crops.	Pastures with specific values: 100 EUR/ha Crops: 25–540 EUR/ha
Organic farming[d)]	For organic animal farming with organic cultivated land and/or semi-natural grasslands. Also for organic crops.	Animal units: 160 EUR/AU Grain, oilseed crops, and protein crops: 150 EUR/ha
Ley production	Production of leys in areas without natural constraints.	50 EUR/ha

[a] Euro (EUR) per ha.
[b] Value for cattle per animal unit (AU).
[c] Support for crops depending on AU per ha and location. Payments for pastures with specific values in addition to payment for maintenance of pastures.
[d] Given to organically farmed crops. If the farm also has animals, additional payments are given. Per AU, the farm must have 1 ha of organically farmed cropland or 2 ha of semi-natural pasture.

reflect the value for the physical food product itself (assuming equivalent quality of the food items). The added premium price for organic farming may in part reflect a value consumers are willing to pay for diverse public goods including non-provisioning ES.

As a proxy for the non-provisioning ES provided by the farms, payments through agri-environmental schemes under the EU Common Agricultural Policy (CAP) (European Parliament and the Council 1305/2013) was used, as done previously by Ripoll-Bosch et al. (2013), Kiefer et al. (2015), and Bragaglio et al. (2020). In this study, agri-environmental payments through the Swedish Rural Development Program (RDP) 2014–2020 associated with the studied cattle production were used (Table 3). The RDP specifies a need to restore, preserve, and enhance ecosystems related to agriculture and forestry, divided into three focus areas; biodiversity restoration, preservation and enhancement; water management; and soil erosion and management. For ES provided by ruminant production in these focus areas, farmers can receive payments for maintenance of pastures and keeping endangered domestic animal breeds (Swedish Board of Agriculture, 2020). In Sweden, payments are given to semi-natural pastures based on a classification into 'general values' or 'specific biological and cultural values' receiving higher payments (Swedish Board of Agriculture, 2020, 2021). Arable and livestock farms maintaining pastures with special values in ANC can also receive payments for contributing to the focus areas (Swedish Board of Agriculture, 2020). Land in ANC risk being abandoned by farmers (Hagyo et al., 2015), which poses risks to ES delivery. According to Hagyo et al. (2015), ANC generally have lower capacity to produce foods, but higher capacity to contribute positively to other ES (*e.g.*, habitat maintenance, pollination, recreation) than areas with more favorable conditions for agriculture. Farmers growing grass-clover leys can receive payments even when not located in an ANC. For contributions to the focus areas, payments are also made for organically farmed crops, with an additional payment for organically farmed animals (Swedish Board of Agriculture, 2020). Compared with conventional systems, organic farming can positively contribute to several ES, *e.g.*, increased biodiversity (Tuck et al., 2014), soil fertility and soil physical properties (Reeve et al., 2016), and improved water quality (Sivaranjani and Rakshit, 2019). Since organic management practices vary, the magnitude of the effect differs between organism groups and landscapes (Bengtsson et al., 2005).

For the economic allocation, the payments were divided into three groups depending on the connection to animal production (Table 4). Group 1 comprised payments directly connected to animal rearing *e.g.* maintenance of semi-natural pastures. Group 2, in addition to the payments in group 1, included payments for organic farming tied to livestock production which also are affected by agricultural land and Group 3 also included payments given for feed production.

Table 4
Grouping of payments used in economic allocation, where group 1 comprises payments directly connected to animal rearing, group 2 also includes payments for organic farming tied to livestock production, and group 3 also includes payments given for feed production.

Group 1	Group 2	Group 3
• Maintenance of semi-natural pastures • Keeping of endangered domestic animal breeds • Maintenance of semi-natural pastures with special values in areas of natural constraints	• Maintenance of semi-natural pastures • Keeping of endangered domestic animal breeds • Maintenance of semi-natural pastures with special values in areas of natural constraints • Organic farming (animal husbandry)	• Maintenance of semi-natural pastures • Keeping of endangered domestic animal breeds • Maintenance of semi-natural pastures with special values in areas of natural constraints • Organic farming (animal husbandry) • Organic farming (feed production) • Feed production in areas of natural constraints • Ley production

3. Results and discussion

3.1. Climate impact without considering non-provisioning ES

The climate impact of beef and milk from the 10 farms when only considering beef, milk, and surplus calves as outputs are shown in Figs. 2 and 3 respectively. For beef, emissions were 13–36 kg CO_2e per kg CW excluding soil carbon stock changes and 16–39 kg CO_2e per kg CW when soil carbon stock changes were included. For milk, emissions were 0.76–1.2 kg CO_2e per kg FPCM excluding soil carbon stock changes and 0.66–1.1 kg CO_2e per kg FPCM when soil carbon stock changes were included. The higher emissions after including carbon stock changes are an effect of soils loosing carbon.

Beef from suckler farms (Suckler A-D) had the highest climate impact, followed by beef from the farm with both suckler and dairy calves (Suckler and dairy calves A). Meat from suckler herds generally has a higher climate impact than meat from dairy herds, as the emissions by the suckler cows are entirely allocated to the beef produced in suckler systems as these do not produce any milk for the market (de Vries et al., 2015). Animals on suckler farms (Suckler A-D) also had lower growth rates and higher slaughter age than animals on dairy farms (Dairy calves A and B), which increased the climate impact as more CH_4 from enteric fermentation was produced during the animal's lifetime and more feed needed to be produced. This confirms previous findings that beef produced on extensive farms commonly has a higher climate impact than beef from intensive farms (Ogino et al., 2016; Bragaglio et al., 2018). Previous research has shown that even with alternative allocation methods, including system expansion, most of the climate impact of dairy systems is attributed to the milk (Cederberg and Stadig, 2003; Baldini et al., 2017). The farm producing milk and fattened calves for beef (Dairy and dairy calves A) had a higher climate impact for beef and milk than the other dairy farms, owing to extensive fattening of surplus calves for beef and lower milk yield. This farm also had a higher fraction of climate impact allocated to beef than the other dairy farms (Dairy A,

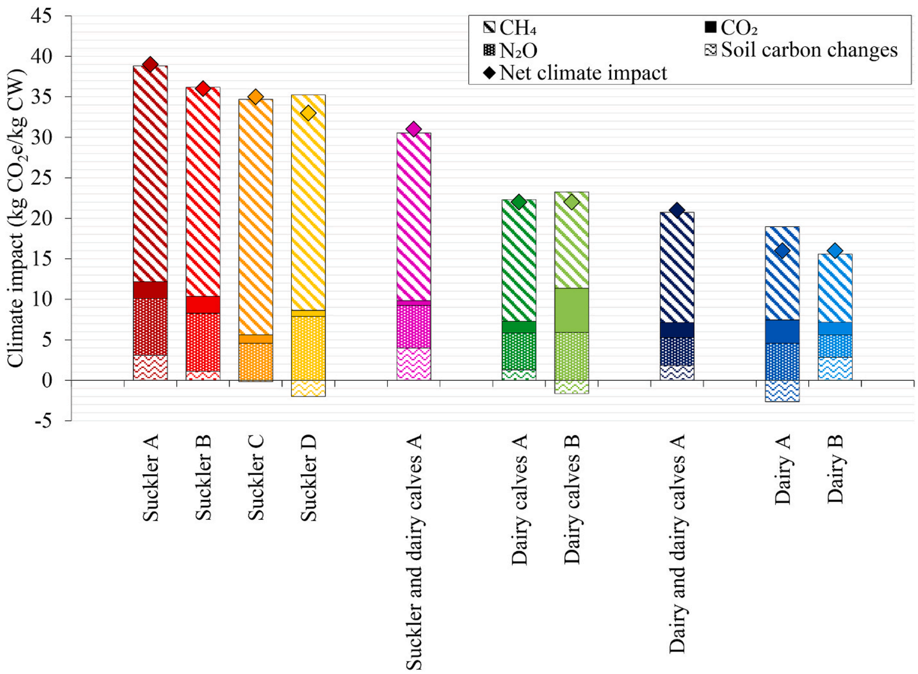

Fig. 2. Climate impact in kg carbon dioxide equivalents (CO_2e) per kg carcass-weight (CW) when only considering beef, milk, and surplus calves as valuable outputs. Impacts are subdivided into carbon dioxide (CO_2) from energy use, land use change and transport, methane (CH_4) mainly from enteric fermentation and manure management, nitrous oxide (N_2O) mainly from manure management and emissions from soils caused by N additions (e.g. crop residues), and CO_2 emissions or sequestration from carbon stock changes. Net climate impacts are also shown.

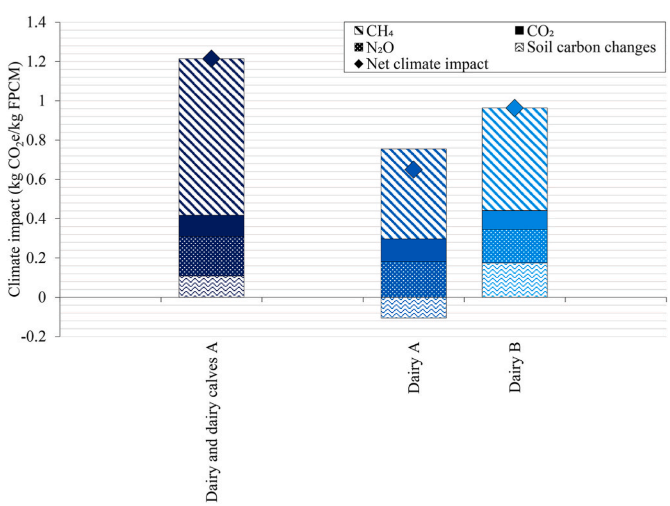

Fig. 3. Climate impact in kg carbon dioxide equivalents (CO_2e) per kg fat- and protein-corrected milk (FPCM) from dairy farms when only considering beef, milk, and surplus calves as valuable outputs. Impacts are subdivided into carbon dioxide (CO_2) from energy use, land use change and transport, methane (CH_4) mainly from enteric fermentation and manure management, nitrous oxide (N_2O) emissions mainly from manure management and emissions from soils caused by N additions (e.g. crop residues), and CO_2 emissions or sequestration from carbon stock changes. Net climate impacts are also shown.

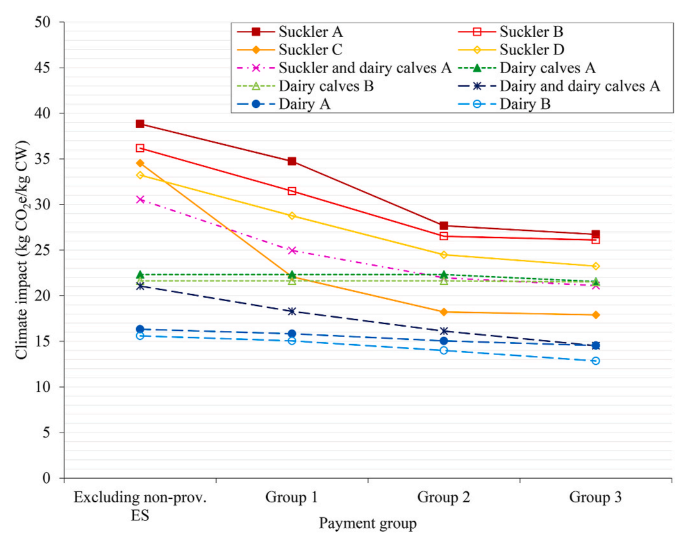

Fig. 4. Climate impact of beef in kg carbon dioxide equivalents (CO_2e) per kg carcass weight (CW) when excluding non-provisioning ecosystem services (non-prov. ES), *i.e.* only including beef and milk for allocation, and when including ecosystem services for allocation using: payment group 1 (payments directly connected to animal rearing), group 2 (also including payments for organic farming tied to livestock production), and group 3 (also including payments for feed production).

B), owing to its higher income from beef due to the value added by including the fattening phase on-farm rather than selling live animals for fattening elsewhere.

Including soil carbon stock changes led to higher estimated climate impact for four of the farms (Suckler A, Suckler B, Suckler and dairy calves A, Dairy B), mostly due to high initial carbon stocks in topsoil in the area where the farms were located, resulting in carbon losses. Soils on three other farms (Suckler D, Dairy calves A, Dairy A) sequestered carbon instead, due to lower initial carbon stocks in those areas. It should be noted that modelling soil carbon changes is associated with large uncertainties, especially for cropping systems consisting of high proportion of leys for which the yield level is difficult to estimate. According to a soil monitoring program in Sweden, decadal carbon sequestration on beef and in particular dairy farms has been substantial but changes in soil organic carbon also show a high spatial and temporal variation between farms (Henryson et al., 2020).

3.2. *Climate impact when considering ES for different farm types*

When also considering non-provisioning ES provided by the farms, as captured by payment-schemes, the difference in climate impact of beef between farms were smaller, 13–27 kg CO_2e per kg CW (instead of 16–39 kg CO_2e per kg CW), allocating <1–48% of the climate impact to

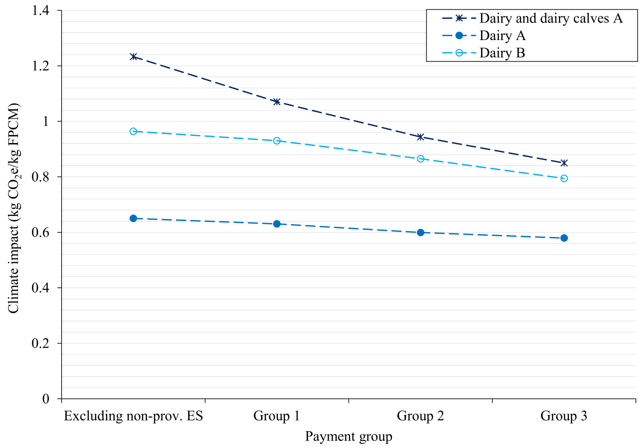

Fig. 5. Climate impact of milk in kg carbon dioxide equivalents (CO_2e) per kg fat- and protein-corrected milk (FPCM) when excluding non-provisioning ecosystem services (non-prov. ES) for allocation and when including ecosystem services for allocation using: payment group 1 (payments directly connected to animal rearing), group 2 (also including payments for organic farming tied to livestock production), and group 3 (also including payments for feed production).

non-provisioning ES (Fig. 4). The climate impact of milk also decreased when considering ES in allocation, from 0.65 to 1.2 to 0.58–0.85 kg CO_2e per kg FPCM, allocating 11–31% of the climate impact to other ES (Fig. 5).

Including non-provisioning ES as an output had the largest effect on the climate impact of beef from suckler farms (Suckler A-D, Suckler and dairy calves A). When group 3 was used for allocation, *i.e.*, including all payments considered in this study, 10–17 kg CO_2e per kg CW were allocated to non-provisioning ES, corresponding to 23–48% of the climate impact. The suckler farms used extensive management methods with low amounts of inputs and high reliance on pasture, resulting in lower growth rates and thus higher slaughter ages. The suckler farms hence produced less provisioning ES in terms of food per ha, but contributed more positively to other ES. Therefore, the allocation method affected the climate impact for beef more than for farms breeding dairy calves more intensively and dairy farms producing both milk and beef. Bragaglio et al. (2020) also found that extensive farms were most affected when including non-provisioning ES but the relative effect was smaller, mainly because the extensive farms they studied used an indoor fattening phase and had higher growth rates than the extensive farms assessed in this study.

Compared with the suckler farms, the specialist dairy farms (Dairy A and B) had a smaller shift in climate impact for beef, with 2–3 kg CO_2 per kg CW allocated to the non-provisioning ES, corresponding to 11–18%. The relative shift for milk was the same, corresponding to 0.17 and 0.07 kg CO_2e per kg FPCM, respectively. In Kiefer et al. (2015), 1–29% of the climate impact from milk was allocated to non-provisioning ES. For their cluster of farms most similar to Dairy A and B (pasture-based with similar milk yields and breed), 8% was allocated to non-provisioning ES, a somewhat lower fraction than for Dairy A and B. However, the payments for managing grasslands were generally lower in Kiefer et al. (2015) (50–120 EUR/ha) compared with this study (100 and 280 EUR/ha). Dairy A and B generated an economic value for non-provisioning ES per ha of the same magnitude as the suckler farms, suggesting a similar positive contribution to ES per land area used. However, since dairy farms generate more income per ha and animal from foods produced (due to the production of milk), allocation factors were less affected by the income from other ES, resulting in a smaller shift. This allocation method should therefore be used with caution when comparing dairy farms with beef farms. In addition, for the farms producing both beef and milk, the allocation method by definition gave the same relative shift for milk and beef, suggesting that milk and beef production contributed equally to non-provisioning ES. However, this may not reflect reality, since on farms producing milk and rearing surplus calves for beef, the latter can potentially contribute more to ES by *e.g.*, longer grazing periods.

The climate impact of beef from Suckler C was most affected by the allocation. Suckler C had the lowest animal density, and therefore provided the least amount of beef per ha. Instead, larger areas of pasture were managed per animal, resulting in more positive contributions to ES per kg CW. Suckler C also received payments for rearing endangered domestic breeds. Similarly, Bragaglio et al. (2020) found that the most extensive system using native breeds was most affected by this allocation method, shifting impacts from the beef to the other services.

Overall, the shift in climate impact to non-provisioning ES (<1–48%) was of the same magnitude as reported by Bragaglio et al. (2020) (0–43%). When comparing dairy farms only, the shift (11–31%) was similar to that in Kiefer et al. (2015) (1–29%). The differences between the studies were partly caused by differences in production, but also by including different payments. Since it is unclear which payments are directly connected to animal rearing, the results depend on the decision of which payments to include. Since the payments vary between countries, the results also reflects nation specific factors, e.g. valuation of ES, politics and finance (Ecorys et al., 2017), making it difficult to compare results across countries. Moreover, the method is sensitive to changes in payments over time, whereby the assumed value of non-provisioning ES also change over time, making it difficult to compare results from different years (Kiefer et al., 2015).

3.3. Variation due to payment schemes included

To analyze the effect of including different payments, they were grouped here according to their level of connection with livestock production. Overall, group 1 payments (maintenance of semi-natural pastures, endangered domestic animal breeds, and maintenance of semi-natural pastures with 'special values' within an ANC) gave a shift of up to 12 kg CO_2e (36%), group 2 (also including payments for organic animal farming) shifted another 0–7 CO_2e (0-18%) from food provisioning to other ES, and group 3 (also including payments for feed production), shifted an additional 0–2 kg CO_2e (0-8%). This indicates that payment schemes that are more directly connected to the ruminant production systems make the largest positive contribution to ES according to how these are valued by society, which is however a result of policy decisions conflated by multiple priorities besides supporting non-provisioning ES (Ecorys et al., 2017). The ANC payments depended on location and animal density, with most farms receiving lower payments for this than for management of pastures. The payment for ley production was lowest of all payments considered. The payments per ha for organic farming of cereals and oilseed crops were higher than for pastures with general values but, since most of the on-farm produced feed consisted of ley, the payment for organic farming of cereals and oilseed crops for feed barely affected the allocations. This resulted in lower payments from feed production than from payments directly associated with rearing of the animals, therefore affecting the allocation factor the least. Suckler A was most affected by group 2 payments, owing to its higher animal density and smaller area of pasture managed than on the other farms. The dairy farms had a smaller area of semi-natural pastures per economic value of products (meat and milk) than the suckler farms, resulting in a smaller effect from group 1 payments. For Dairy and dairy calves A, group 3 payments had a larger effect on allocation than on the other farms, explained by this farm being located within an ANC with higher payments. This indicates that the support for feed production can be important for farms producing their own feed if located in a specific ANC.

In this study, ES connected to the focus areas in the Swedish RDP were considered, *i.e.*, "Biodiversity restoration, preservation and enhancement", "Water management" and "Soil erosion and soil management", as the payment schemes provide an economic value indicating what society is currently paying. Non-material services such as physical and psychological experiences, are difficult to value economically, but some may be indirectly captured through payments for *e.g.*, maintenance of semi-natural pastures that are associated with cultural values (Karlsson et al., 2022).

A potential alternative to economic allocation based on payment schemes is to use a scoring method to score the (capacity for) delivery of provisioning and other ES from the system under study and base allocation on these scores, as suggested by (Boone et al., 2019). This could avoid assumptions on how well payment schemes capture the supply of ES and allow for the inclusion of more ES (not covered by payment schemes) but would necessitate some procedure to weigh the importance of different ES. Boone et al. (2019) assumed an equal weight on provisioning and regulating ES, which is unlikely to accurately reflect how different ES are valued in society. This valuation could however be done with e.g. choice modelling where different stakeholders are asked to value different ES (Faccioni et al., 2019). Deriving allocation factors this way would however be sensitive to which stakeholders are included in choice experiments (Bernués et al., 2014) and deriving transparent, non-context specific and generalizable factors may be hard. Using income from payment schemes avoids this by assuming that the size of these payments reflects society's prioritization between different ES.

3.4. Using climate impact values for beef with emissions allocated to ES

Results from LCAs are used as decision support in a range of applications in the food system, including labeling for consumer communication, monitoring of environmental impacts in food production for policy development and evaluation, and guiding environmental improvements of industry's food production (Notarnicola et al., 2017). Food companies are increasingly using climate impacts as part of consumer communication. For example, the Swedish online retailer Mat.se labels 3000 food products with their carbon footprint[1] and ICA, the largest retailer in Sweden, provides its loyalty card holders with a monthly summary of aggregated emissions from their food purchases.[2] These measures are intended to act as drivers in reducing GHG emissions through influencing consumer choice, *i.e.,* consumers choosing products with lower climate impacts, and through improvements in production, *i.e.*, food producers (farmers and food industry) lowering emissions through efficiency improvements, technological advances, reduced waste, or changes in ingredients in composite foods. More intensive beef production systems tend to have lower climate impacts per kg of meat than extensive, multifunctional systems. Therefore, there is a risk of pushing production systems towards more intensive production when non-provisioning ES are not considered in the climate impact calculations. This would neglect important values that multifunctional ruminant systems could deliver. Including non-provisioning ES in climate impact calculations, as done in this study, can reduce this risk. Another option could be to label or monitor the outcomes for non-provisioning ES alongside climate impacts and present several environmental indicators for each food product. For example, the Swedish retailer COOP provides sustainability declarations for some products based on 10 sustainability indicators[3] (climate, biodiversity, soil fertility, water, pesticide use, eutrophication, animal welfare and use of antibiotics, working conditions, local community, rule of law and tractability) in a 'spider's web' diagram. This covers a greater range of sustainability aspects, which is important for foods considering the potential trade-offs. However, it also leaves the consumer to weigh these aspects, increasing the complexity in consumer communication (Ströbele and Lützkendorf, 2019). Considering non-provisioning ES as an output of the system and allocating some of the climate impact to these ES might be a more straightforward solution that has the simplicity of just one indicator, climate impact, while considering the benefits of multifunctional systems. However, use of this method in practice can be challenging as impacts can vary over time and country, due to changes and differences in payment schemes, making it difficult to fairly compare products. More research is needed into the practical use of ES-corrected climate impact.

An actor in the food system that could benefit from including ES in climate impact assessments is the Swedish organization KRAV, (that develops standards for organic certification, in addition to the EU regulations) which from 2022 requires all farms larger than 200 ha to calculate and report their climate impact (KRAV n. d.). At the time of writing it is unclear how KRAV will use the climate impact data. If used to compare farms in terms of climate impact per kg food produced, in order to incentivize reductions in emissions by certified farmers, it could lead to intensification of organic farms and compromised animal welfare and biodiversity outcomes (Röös et al., 2018). Considering non-provisioning ES in the climate impact calculations could alleviate that risk, as delivering more ES would also be a way to improve the climate impact value.

In all applications of ES-corrected climate impacts, it is important to acknowledge that emissions will not disappear, but will only be shifted from beef or milk to other ES provided. To reach climate targets, very drastic cuts in emissions are needed, including in food systems and agriculture (Clark et al., 2020). Thus, when impacts are shifted from foods to other ES, reducing emissions from provision of these ES must not be forgotten. For example, semi-natural pastures can be managed for biodiversity conservation in more or less climate-impacting ways. According to Röös et al. (2016), managing these pastures with suckler herds instead of animals from dairy production is more climate-efficient per ha managed land as it requires fewer animals in total (since suckler cows have longer grazing periods than dairy cows). This was confirmed in the present study, where Suckler C delivered non-provisioning ES at a much lower total climate cost per ha than the other farms, as fewer animals grazed a larger area and animal feed intake was dominated by grazed biomass. Since managing emissions from ES might be the responsibility of policy makers for the food system, rather than farmers or consumers, allocating emissions to the additional ES could make this responsibility more transparent and explicit.

4. Conclusions

Including non-provisioning ES in addition to food provisioning services when attributing the climate impact from ruminant systems had a large effect and was affected by different ways of coupling ES to livestock through payment schemes. Including payments for ES most directly associated with animals (here represented by payments for management of pastures and endangered domestic breeds) had the largest effect on the climate impact, while ES related to feed production had a smaller effect. The magnitude of the effect from the different coupling approaches depended on animal density, location, and area of semi-natural grasslands, as an outcome of policy decisions on compensatory payments. Including non-provisioning ES in the allocation resulted in <1–48% and 11–31% of the climate impact being shifted from beef and milk, respectively, to other ES. Suckler farms were most affected, while dairy farms had a smaller shift owing to high production of milk. ES-corrected climate impact can potentially be useful as part of consumer communication or as a decision tool for policy makers and industry, reducing the risk of neglecting non-provisioning ES provided by ruminant production in a simpler way than using separate indicators. However, it is important to note that emissions do not disappear, but are only shifted from beef and milk to other ES.

[1] https://www.mat.se/mat-klimat.

[2] https://www.ica.se/buffe/artikel/mitt-klimatmal-info/.

[3] https://www.coop.se/hallbarhet/hallbarhetsdeklaration/.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2022.116400.

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