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Research article

Environmental and biodiversity effects of different beef production systems

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ABSTRACT

Agricultural livestock production ranks among the most environmental impactful industry sectors at the global level, and within the livestock sector, beef production accounts for a large proportion of environmental damage. Beef production in Alpine mountain regions, such as in South Tyrol (Italy), is a small, but increasing agricultural sector. Thus, the aim of this study was to examine the environmental impact of different organic and conventional beef production systems in South Tyrol and to compare their environmental impact and effect on biodiversity under Alpine production conditions. Live cycle assessment (LCA) approach was used and 1 kg of live weight (LW) was chosen as functional unit (FU). Global warming potential (GWP, kg CO_2-eq), acidification potential (AP, g SO_2-eq), eutrophication potential (EP, g PO_4-eq), non-renewable energy use (NRE, MJ-eq), land occupation (LO, m^2 organic land/year) and biodiversity damage potential (BDP) expressed in potential disappeared fraction (PDF) were investigated. The study involved 18 beef cattle farms in the South Tyrolean region: Conventional calf-fattening farms (CCF = 6), organic suckler cow farms (SCF = 6), and conventional heifer/ox fattening farms (HOF = 6). The CCF system showed a higher environmental impact compared to SCF and HOF systems for all impact categories ($P < 0.05$). Between the organic and the conventional system (SCF and HOF), no significant differences ($P > 0.05$) were found for most of the considered impact categories (means ± SEM per FU): GWP: 19.8 *vs* 17.1 ± 4.2 kg CO_2-eq, AP: 11.4 *vs* 9.3 ± 4.7 g SO_2-eq, EP: 4.1 *vs* 2.8 ± 1.2, NRE: 21.9 *vs* 13.8 ± 7 MJ-eq, SCF and HOF respectively. Only for LO (70.8 *vs* 44.1 ± 17.7 m^2 organic/y, $P < 0.01$, SCF and HOF respectively) and the effect on BDP (−1.93 *vs* −0.85 ± 0.35, PDF, $P < 0.01$, SCF and HOF respectively) differences between organic and conventional production methods could be revealed. The study showed that beef cattle husbandry in the Alpine area has a satisfactory environmental performance. In particular, the systems studied showed a positive impact in terms of biodiversity.

1. Introduction

Livestock production systems rank among the most environmental impactful activities at the global level. The global human demand and production of animal products are rapidly increasing, due to the population growth, and changes in lifestyle and diets (Salter 2017). The livestock sector is responsible for about 14.5% of all anthropogenic emissions Gerber et al. (2013) Mitigation strategies are being sought most is the livestock sector, in particular the beef production. Cattle account for about 65% of total emissions from the livestock sector, with beef production accounting for around 40% (de Vries et al., 2015). Life Cycle Assessment (LCA) is a general approach, accepted by the European Union (EU), for estimating the environmental impacts that a functional unit of product causes during its entire life cycle. Several studies on the impacts of livestock enterprises were based on the application of LCA. These studies involved dairy cattle (Salvador et al., 2017; Pirlo and Lolli, 2019; Sabia et al., 2020a), beef cattle (Bragaglio et al., 2018; O'Brien et al., 2019; Chen et al., 2020), dairy buffaloes (Sabia et al., 2018a; Sabia et al., 2015), and dairy sheep (Vagnoni and Franca, 2018; Sabia et al., 2020b). Several studies showed that beef production contributes significantly to the emission of natural greenhouse gases (GHG) and some beef production systems thus carry a high environmental load (Lynch, 2019; Mazzetto et al., 2020). However, a large variation of the environmental impact of beef cattle farming was revealed. For instance, emissions of GHG vary from 8.6 to 35.2 kg CO_2 equivalents per kg of edible beef (de Vries et al., 2015). Recent studies agree that these disparities are mainly due to different methodological approaches but also due to fundamental differences among beef production systems (de Vries et al., 2015; Bragaglio et al., 2018). These differences are due especially to the origin of the calves, the type of feeding (e.g. low vs. high amount

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of concentrates and pasture vs. conserved roughage and/or maize feeding), and the duration of the fattening period. Beef production in mountain regions, such as in the study area South Tyrol, is generally characterised by extensive production systems due to the lack of arable land. South Tyrol is situated in the very Northern part of Italy and is characterised by a typical Alpine landscape with 86% of the total area above an altitude of 1000 m. Due to the mountainous landscape, only about half of the total agricultural area is suitable for cultivation (211,000 ha). In 2018, about 8000 livestock farms were present which focused mainly on cattle breeding and kept about 128,000 cattle, of which 66,600 were dairy cows (Autonome Provinz Bozen-Südtirol, 2019). Currently, there are only a few valid numbers regarding beef cattle farming available. However, the 42 South Tyrolean slaughterhouses slaughtered about 10,600 cattle in 2016 (Busch et al., 2018). Livestock farms in the study area are generally small with an average of 7 ha of agricultural land and an average herd size of 16 cattle per farm (Astat, 2013). Due to the relatively small size, more than half (56.9%) of the livestock farms are managed as a side-line activity (Astat, 2016). Beef production, and in particular suckler cow farming, is less labour intensive than dairy farming and allows the farmer more flexibility in terms of worktime management (Greimel et al., 2002). Thus, beef cattle husbandry could be a future management strategy for many small farms. The use of Alpine pastures for cattle grazing during the summer months is very common among South Tyrolean livestock farms. The positive environmental effect can increase if less favoured, non-arable areas are used for cattle grazing (Wiedemann et al., 2015). In addition, Alpine pasturing demonstrably contributes to the preservation of various ecosystems and the provision of important ecosystem services, while at the same time increasing the touristic attractiveness of a region (Tasser et al., 2005; Streifeneder et al., 2007; Bernués et al., 2011). If these remote Alpine pastures are abandoned, they will encounter the natural process of succession leading to an increase of erosion and a decrease of biodiversity (Tasser et al., 2005; Scotti et al., 2020). Until now, only few studies have investigated the effect of meat production on biodiversity (Pogue et al., 2018; Crenna et al., 2019; Koncz et al., 2020). Including the biodiversity implications of production processes such as beef cattle is increasingly necessary (Crenna et al., 2020). Environmental aspects become increasingly important to consumers and demand for safe and high quality products is rising (Streifeneder et al., 2007). The environmental friendliness of an agricultural product may be a key issue for future marketing strategies, especially for products from less productive mountain areas. Even though organic production is often believed to be more environmental friendly than conventional production, studies revealed that organic cattle systems might lead to higher greenhouse gas emissions per kg beef than conventional ones because they are less productive (Williams et al., 2006). Buratti et al. (2017) confirmed these findings for organic and conventional beef production in the Italian context. Thus, the aim of this study is to examine the environmental impact of different organic and conventional beef production systems in South Tyrol and to compare their environmental impact and their effect on biodiversity under Alpine production conditions.

2. Material and methods

2.1. Definition of goal and scope

The boundaries of the LCA model for evaluating the environmental assessment in South Tyrol beef production system were set as follows: the approach used for all three systems under study was cradle-to-farm gate. Midpoint impact assessment (Sabia et al., 2018b) considered global warming potential (GWP, kg CO_2-eq), acidification potential (AC, g SO_2-eq), eutrophication potential (EP, g PO_4-eq), non-renewable energy use (NRE, MJ-eq), land occupation (LO, m_2 organic arable land/years) and biodiversity damage potential (BDP). 1 kg of live weight (LW) of marketed beef cattle was the functional unit (FU). The midpoint impact assessment was carried out by the commercial software SimaPro, and module method was EPD 1.04 (2008), by the data base Ecoinvent 3.3.

2.1.1. Biodiversity impact estimation

The estimation of effect on biodiversity expressed in terms of BDP used the characterisation factors (CFs) for land use type and potentially disappeared fraction (PDF) (Knudsen et al., 2017, 2019), this approach is based on a set of data collected in six different European countries:

$$\mathrm{BDP} = \mathrm{CFs} \times t \times A;$$

Where:

CFs = characterisation factor for permanent grassland was -0.36 PDF m^{-2} for organic farms, and -0.23 for conventional farms, whereas it was 0.68 PDF m^{-2} (Knudsen et al., 2019) for all other intensive crop production systems.

t = time in year; A = area in m^2

2.2. Beef production systems boundary

This study involved 18 beef cattle farms in the South Tyrolean region (Italy). The farms included were selected according to their beef production strategy. In South Tyrol, three types of beef cattle farms prevail: calf-fattening farms (CCF), suckler cow farms (SCF), and heifer/ox fattening farms (HOF). In this study, six farms of each type were included.

The three system-boundaries are shown in Fig. 1a, b and c. The CCF farms buy the calves bred by dairy farms at the age of two or three weeks and feed them with milk replacers or cows' milk up to a slaughtering age of four to five months and a live weight of approximately 190 kg. The SCF farms breed their own calves and therefore have an own herd of beef cows. The slaughter age of the calves varies between eight to twelve months. Until this age, the calves are nursed by their mothers and kept together in a herd. They reach an average live weight of 414 kg. The HOF farms buy the calves they use for further fattening from dairy farms at the age of three to four weeks and feed them with milk replacers up to an age of four months. After this nursing period, the animals are fed hay, concentrates and grass on pasture up to a slaughter age of 24–30 months and live weights of 620 kg. All SCF farms in this survey operated according to EU organic production standards while all CCF and HOF farms managed their farms in a conventional way. However, all participating farms are characterised by the total absence of the use of organic and inorganic synthetic fertilizers and pesticides. Therefore, the main differences between organic and conventional farms in our study can be mainly found in the type of animal husbandry (e.g. medical treatments, barn system) and not so much in the management of the grassland area.

In summary, the main differences between the three systems lay in the origin, husbandry and feeding of the calves, the duration of the fattening period and the type of farm management (conventional or organic). To collect the primary data, beef cattle farmers were interviewed between February and May 2018. The questionnaire consisted of different sections with questions about farm structure, husbandry and feeding system. All data regarding farm size, livestock number and fattening period, feeding, grazing, purchased feed, fuel and electricity consumptions were collected in detail and are shown in Table 1.

2.3. Emissions calculations

Appendix S1 shows the equation used for the calculation of the emissions generated by the studied systems considering all on-farm and off-farm activities. Methane (CH_4) biogenic from enteric fermentation, manure storage and manure directly deposited on the grassland were calculated by Tier 2 equation suggested by the international panel on

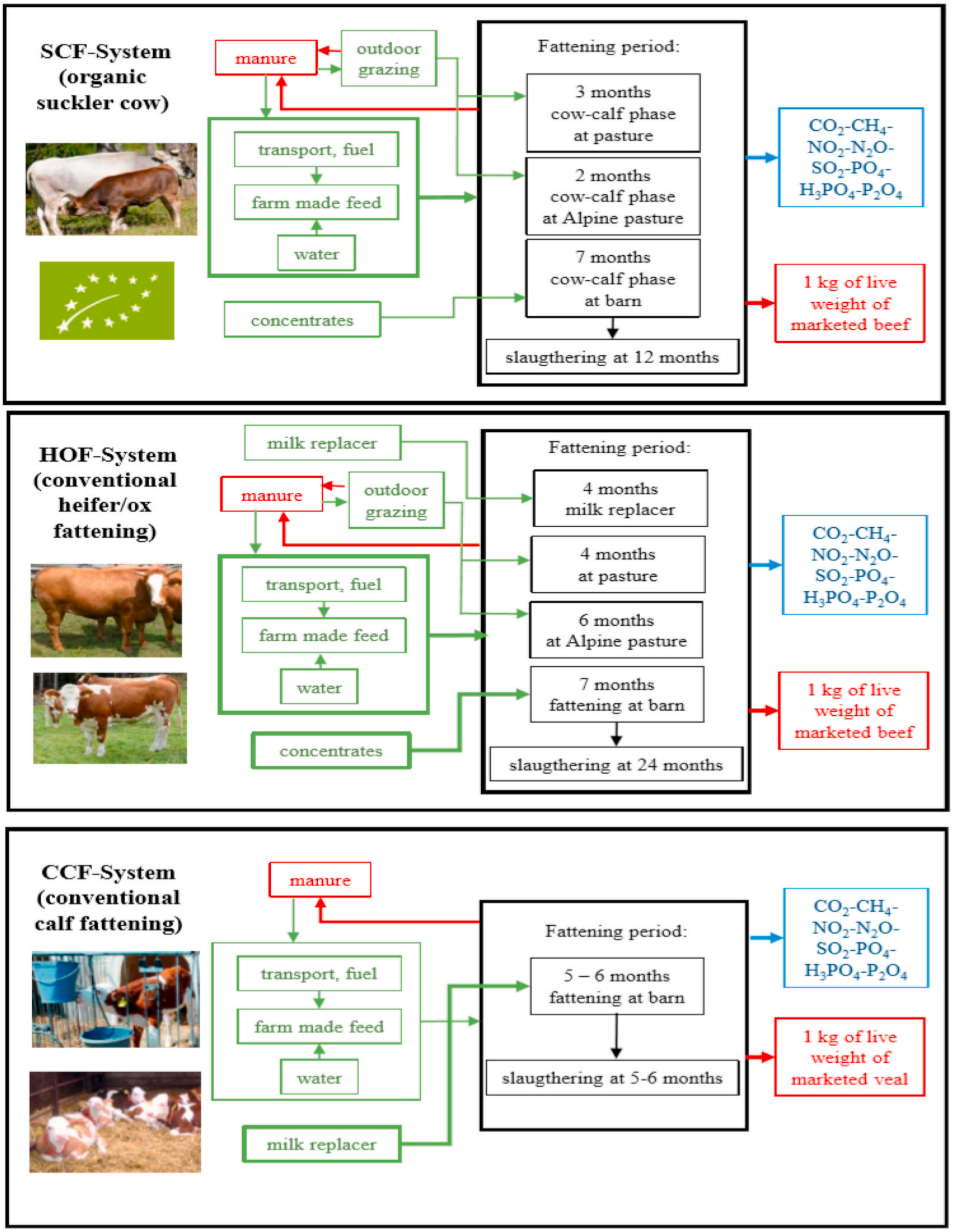

Fig. 1. System boundaries of the three beef production systems. Green, red and blue arrows indicate inputs, outputs and emissions, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

climate change (IPCC 2006a). Methane conversion factor (Y_m) was 4% for young calves in CCF system, whereas it was 6.5% for SCF and HOF systems. Manure CH_4 emission volatile solid (VS) was 3.9 kg/animal/-day (IPCC 2006a), maximum CH_4 production capacity was 0.1 m^3/kg VS and methane conversion factor (MCF) was 27 for pit storage whereas it was 1.5 for pasture. Direct and indirect N_2O emissions occurring on pasture during grazing were estimated following the IPCC equation. The amount of nitrous oxide emitted from manure based on total N excretion was estimated and the country-specific emission factors of 0.02 kg of N–N_2O/kg of excreted N for Italy was used (Cóndor et al., 2011). Considering the direct N soil deposition, an emission factor of 0.0125 kg N–N_2O/kg N was used (Cóndor et al., 2011). Indirect emissions of N_2O were estimated according to the method suggested by IPCC (2006b) based on nitrate leaching-runoff, and re-deposition of volatised gases to soils and waters. In particular, for indirect deposition from the atmosphere an emission factor of 0.01 kg N_2 O–N/kg N was used, whereas 0.025 N–N_2O/kg N was used for N leaching-runoff as suggested as an Italian country-specific emission factor by Cóndor et al. (2011). Carbon dioxide (CO_2) emitted during energy consumption, either directly from the combustion of fossil fuels or indirectly from electricity use, was estimated taking into account the amount of diesel fuel in litres and the amount of electricity in kWh consumed throughout farm operations (Table 1). As suggested by ENAMA (2005), a standard value of 0.85 kg per litre as diesel density and a 3.13 kg CO_2-eq. emission factor to

Table 1
Characteristics of the beef cattle farms located in the South Tyrolean Alpine region, (mean ± S.E.M.).

	CCF (n = 6)	SCF (n = 6)	HOF (n = 6)	S.E.M.
Beef calves (n)	5.7	7.3	12.7	4.3
Cows (n)	4.9^{A}	8.5^{A}	1.0^{B}	1.3
Body weight fattening (kg)	189^{A}	414^{B}	618^{C}	23
Permanent grassland (ha)	5.2^{a}	10.4^{b}	5.4^{a}	2.1
Days on pasture	0^{a}	108^{b}	95^{b}	21
Permanent grassland (kg/DM/y)	$36{,}306^{a}$	$73{,}074^{b}$	$39{,}783^{a}$	11,591
Feed concentrate (kg/farm/y)	3258^{a}	991^{b}	3641^{a}	1025
Electricity (KWh/y)	2874^{a}	4726^{b}	3142^{a}	1314
Diesel (L)	840	982	1206	274

CCF: calf-fattening farms; SCF: suckler cow farms; HOF: heifer/ox fattening farms; S.M.E.: Standard error of mean; DM = dry matter.
ab, $P < 0.05$; ABC, $P < 0.01$.

estimate CO_2 release from the combustion of 1 kg of diesel were used, whereas for electricity an Italian-specific emission factor of 0.47 kg CO_2-eq 1 kWh was considered (Còndor, 2011). In the LCA, the characterisation factors used for GWP were 1, 34, and 298 CO_2-eq for CO_2, CH_4, and N_2O respectively. These values were suggested by Gillett and Matthews (2010) and indicated in a report by Myhre et al. (2013) (Table 8.7) and in the report from FAO (2018).

2.4. Statistical analysis

The data at farm level, GWP, AP, EP, NRE, LO, BDP, main processes and main pollutants were analysed by using one-way (general linear model procedure) ANOVA, using the farming systems as a factor. The data set was normally distributed and was analysed using SAS software (SAS Institute Inc.,Cary, NC). All significance levels are related to $P \leq 0.05$.

3. Results and discussion

3.1. Farm level

Table 1 shows the main characteristics of the beef farms under study. The number of fattening animals per farm and year was small with an average livestock number ranging from six (CCF) to 13 (HOF) fattening animals per farm and cowherds consisting of only one (HOF) to nine (SCF) animals. Permanent grassland area ranged from five (CCF and HOF) to ten (SCF) hectares per farm. The organic system showed a significantly higher average permanent grassland area than the two conventional systems ($P < 0.05$); this was most probably due to the fact that organic systems, either for beef cattle or dairy cows, require a greater amount of on-farm resources than off-farm resources (Peters et al., 2010; Blanco-Penedo et al., 2019). Among the three studied systems, the CCF-farms were the smallest ones in terms of number of fattening animals and in terms of permanent grassland area. However, the small farm sizes are representative for the study area, since most of the South Tyrolean livestock farms cultivate only small agricultural areas with average values of 7 ha and average herd sizes of 16 cattle per farm (Kühl et al., 2020). The three systems were differentiated by weight and age at slaughter. CCF farms slaughtered their calves at a mean body live weight of 189 kg. Cozzi (2007) observed that calves fattened in Italian farms are slaughtered at an average live weight of about 243 kg, whereas Morel et al. (2016) observed an average live weight of 350 kg at the age of about 8 months. The organic system showed a live weight of 414 kg at the age of about 12 months while the conventional showed a live weight of 618 kg at the age of two years of life. Buratti et al. (2017) observed a higher animal performance of about 12% compared to our study, whereas Cerri et al. (2016) observed similar results compared to our study. The lower performance was most likely due to the lower use of concentrated feed in all three South Tyrolean beef farming systems. Among the milk calf producers, the use of pasture is not common since consumers ask for light coloured veal and animals should therefore be kept in closed barns for the entire fattening period (Cozzi, 2007) with no access to pasture. On the contrary, the fattening animals on the SCF (108 days) and HOF (95 days) farms spend about three months of the year on pasture. Permanent grassland yields in terms of kg dry matter per year ranged from 36,000 kg (CCF) to 73,000 kg (HOF) per farm. According to Peratoner et al. (2010), the estimated self-supply rate of forage for the South Tyrolean livestock farms amounts to 70%–80%. The studied farms reached an even higher self-supply rate, since most of them did not purchase forage at all. The highest amounts of concentrates per farm and year and also per animal were used for heifer/ox fattening and calf fattening, while the suckler cow farms used on average considerably less concentrates. All concentrates used for beef production derived from off-farm sources, since the study area offers no possibilities for the on-farm production of cereals due to climatic and topographic constraints. SCF farms showed the largest consumption of electricity per year and farm. A possible explanation could be their relatively larger size in terms of animal number and hectares compared to the CCF and the HOF farms. Fuel consumption showed no significant differences between the studied systems.

3.2. Environmental impact

It can be observed that the CCF system showed significantly ($P < 0.05$) higher values for all environmental impact categories than the other two systems. Regarding the effect on biodiversity, the organic system showed the highest positive performance compared to the other systems. A detailed description and discussion of the different impact categories involved in different processes and pollutants for each beef production system under study is given below.

3.2.1. Global warming potential (GWP)

The CCF system showed a significantly higher impact of GWP per 1 kg of LW than the other two systems ($p < 0.05$), while no significant differences were found between the SCF system (19.8 kg CO_2-eq/kg LW) and the HOF system (17.1 kg CO_2-eq/kg LW) (Fig. 2). The CCF farms in our study used no pasture and all animals were confined during the entire fattening period in closed barns. CCF production system includes several farm inputs for the dairy cows' maintenance such as feed concentrate (3258 kg/farm/y) and diesel and electricity consumption. All this creates a high environmental impact but generates a very low output (189 kg LW per calf), compared to other studies (Bedoin and Kristensen, 2013). Improving the production performance of dairy calves could help increase the environmental performance of the system. Table 2 shows the percentage impact of the different processes in terms of GWP. In the CCF system, the main process affecting GWP was the enteric emissions (53.7%) followed by general consumption (17.2%). The main pollutant was methane biogenic (54%) followed by CO_2 (29.4%) (Appendix S2). According to Nguyen et al. (2010) the GWP in

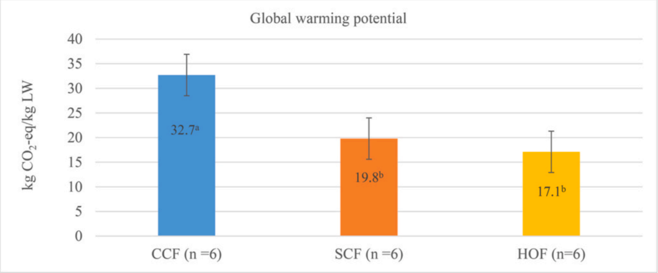

Fig. 2. Global worming potential in the three different beef production systems per 1 kg live weight (LW), (means ± S.E.M.).

Table 2
Percentage of the different processes involved on the impact to global warming potential in the different beef production systems.

%	CCF (n = 6)	SCF (n = 6)	HOF (n = 6)	S.E.M.
Enteric fermentation	53.7^{a}	33.4^{b}	70.8^{c}	4.9
General consumptions	17.2^{a}	22.7^{ab}	8.4^{c}	3.2
Permanent grassland	14.4^{a}	29.0^{b}	10.0^{a}	2.9
Concentrate production	10.5	9.0	6.0	2.0
Manure management	3.2^{a}	4.7^{b}	3.7^{a}	0.3

CCF: calf-fattening farms; SCF: suckler cow farms; HOF: heifer/ox fattening farms.
ab, $P < 0.05$; ac, $P < 0.01$; bc $P < 0.01$.
Cutt-off 0.1%.

the EU ranges from 16.0 to 27.3 kg CO_2-eq per kg meat slaughter weight. The slaughter weight can be estimated as a maximum of 60% of the live weight of beef cattle (Steinwidder 2012). Therefore, the results found by Nguyen et al. (2010) would correspond to a range of 26.7–40.5 kg CO_2-eq per kg live weight. Bragaglio et al. (2018) found GWP values of 18–26 CO_2-eq per kg live weight in four different Italian beef production systems, whereas Buratti et al. (2017) observed a value between 24.64 and 18.21 kg CO_2-eq/kg LW. However, Ruviaro et al. (2015) observed a GWP of 18.3 kg CO_2-eq in the intensive system (animals slaughtered at a live weight of 430 kg and an age of 502 days) and 42.6 kg CO_2-eq at an age of 840 days in the extensive system. In a study conducted in Switzerland, Alig et al. (2012) observed a better performance in terms of GWP in organic systems than conventional systems, while Casey and Holden (2006) showed results approximately equal to half the values we estimated. Recent studies showed that intensive beef production mitigates certain environmental impacts such as GWP and intensive systems reach thus lower GWP values than pasture-based systems (Berton et al., 2017; Bragaglio et al., 2018). Picasso et al. (2014) showed that GWP of beef from suckler calves, which were raised on lowly productive pastures in Uruguay, was more than twice as much as the GWP generated by calves pastured on seeded grasslands and finished in feedlots. Generally, the higher GWP of beef produced on low productive grassland can be explained by the reduced animal growth and performance (de Vries et al., 2015). SCF and HOF farms used pasture areas and let their animals graze on them for more than three months of the year (Table 1). A shift from low productive grassland to intensive fattening could reduce GWP (e.g. (Dick et al., 2015; Ruviaro et al., 2015) but leads to other negative effects for the ecosystems, such as habitat and wildlife loss, soil erosion and nutrient run-off. In addition, animal pasturing has an important positive influence on the touristic attractiveness and the landscape aspect of a region. This aspect cannot be neglected especially for Alpine regions, where tourism is an important economic factor (Tasser et al., 2007). In addition to the husbandry system, the origin of the calves can influence GWP. Several studies showed that GWP was on average 41% lower for dairy-based systems compared with suckler-based systems (de Vries et al., 2015). However, our results are in line with other studies conducted in the European Union (Berton et al., 2017; Eldesouky et al., 2018; Bragaglio et al., 2020). Enteric fermentation makes up for the greatest proportion of GWP (Table 2). The lowest incidence of enteric fermentation was found for SCF, where also permanent grassland and general consumptions represented a considerable share in terms of GWP. The HOF system showed the highest significant incidence for enteric fermentation with more than 70%. This was most probably due to the longer duration of the production cycle and therefore to a greater use of the grazing resource. Similar results were observed by Bragaglio et al. (2018) in exclusively extensive beef farming systems with values above 80%, while in specialised intensive beef production systems the values ranged from 10 to 40% for enteric emissions (Berton et al., 2017; Bragaglio et al., 2018). These differences are most probable due to the different qualities of forage feed and to the different amounts of concentrates fed to the animals. The influence of concentrate production was highest for the CCF system, while manure management had a relatively low influence on GWP for all three systems. The main pollutants involved in the impact of GWP were methane biogenic, carbon dioxide and dinitrogen monoxide. Methane showed the largest share for the CCF and the HOF system, while in the SCF system carbon dioxide was the main pollutant (Appendix S2).

3.2.2. *Acidification potential (AP)*

The highest AP was found for the CCF farms, followed by significantly lower values for SCF and HOF farms ($P < 0.05$), (Fig. 3). Recent studies showed considerable higher results for AP in different beef production systems. Bragaglio et al. (2018) found AP values ranging from 200 to 300 g SO_2-eq per kg live weight, while Nguyen et al. (2010) found AP results within a range of 101–210 g SO_2-eq per kg slaughter weight (corresponding to an estimated value of 116–333 g SO_2-eq per kg live weight). Berton et al. (2017) showed a value equal to 193 g SO_2-eq for an intensive beef production system in Italy. The very low AP values in the three studied production systems can be mainly explained by the complete absence of the use of artificial fertilisers, since none of the farms purchased or used them. In addition, the studied farms rarely purchased forage. According to Bragaglio et al. (2018), the amount of feed purchased and NH_3 emissions from housing and manure storage increase the AP of a system. Only a few studies compared certified organic and conventional beef production systems in terms of AP (e.g. Presumido et al., 2018). However, Williams et al. (2006) and Alig et al. (2012) found 56% higher AP in organic systems compared with conventional systems. Our study does not confirm these results, since the CCF system showed a nearly three times higher AP than the certified organic production system (SCF). Table 3 shows that concentrate production influenced AP the most in CCF farms (60%), followed by 52% in HOF and relatively low values in the SCF system (36%). These results are in agreement with several other studies, which showed that the largest source of emissions of SO_2 -eq from beef and milk production is the feed concentrates production (Castanheira et al., 2010; Bragaglio et al., 2018). On the other hand, permanent grassland was the main contributor to AP in the SCF system (61%). Current literature shows contradictory results: while Nguyen et al. (2010) found that AP was higher for roughage-based systems compared to concentrate-based systems, Lupo et al. (2013) and Presumido et al. (2018) found quite the opposite. Among the main pollutants, nitrogen oxide was the most important one (especially in the SCF systems; Appendix S3), followed by ammonia and sulphur dioxide. In the SCF system, ammonia only had a minor incidence on AP (only about 10%), while its percentage was much higher in the CCF and the HOF system. The proportion of sulphur dioxide was nearly the same in all three systems (about 20%). However, our results are in agreement with previous studies (Bragaglio et al., 2018; Presumido et al., 2018).

3.2.3. *Eutrophication potential (EP)*

Impact generated by the three beef farming systems in terms of EP expressed in g of PO_4 – eq, Fig. 4. EP was highest for CCF farms followed

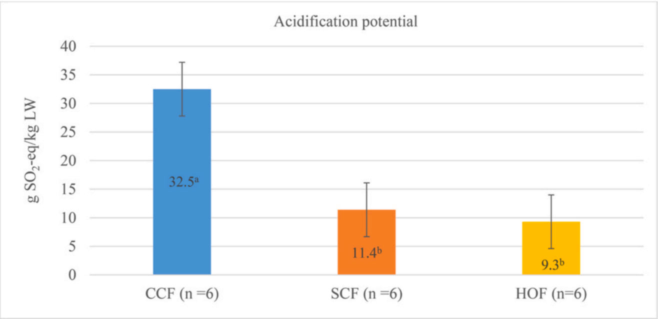

Fig. 3. Acidification potential in the three different beef production systems per 1 kg live weight (LW), (means ± S.E.M.).

Table 3
Percentage of the different processes involved on the impact of acidification potential in the different beef production systems.

%	CCF (n = 6)	SCF (n = 6)	HOF (n = 6)	S.E.M.
Concentrate production	60.1^a	35.9^b	51.5^c	6.1
Permanent grassland	38.6^a	61.0^b	41.9^a	8.7

CCF: calf-fattening farms; SCF: suckler cow farms; HOF: heifer/ox fattening farms.
ab, $P < 0.05$; ac, $P < 0.01$; bc $P < 0.01$.
Cut-off 0.1%.

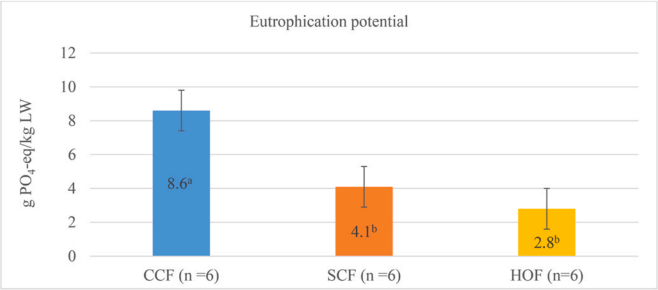

Fig. 4. Eutrophication potential in the three different beef production systems per 1 kg live weight (LW), (means ± S.E.M.).

by significantly lower results for SCF and HOF farms (Table 4). However, the EP of all three studied systems was clearly lower compared to the results obtained by other studies. Pelletier et a. (2010) found EP values ranging from 104 g PO_4-eq per kg live weight (feedlot system) to 142 g PO_4-eq per kg live weight (pasture-based system), whereas lower values (about 50 g PO_4-eq/kg LW) were observed by Zonderland-Thomassen et al. (2014) and Berton et al. (2017). However, Dick et al. (2015) found higher EP values in intensive systems compared with extensive one. Most probably the low results observed in terms of EP were due to the total absence of inorganic fertilizers, such as nitrogen, phosphorus and potassium, which are mainly responsible for the phenomena of eutrophication of inland and costal water (Huang et al., 2017). In addition to that, also a low livestock density index of the farms contributes to the low EP values (Zonderland-Thomassen et al., 2014). The percentage impact on EP was highest in terms of concentrate production for the CCF and the HOF system (Table 4). For the SCF system, permanent grassland had the strongest influence on EP. These findings are in agreement with Nguyen et al. (2010) who found that emissions from feeding inputs during the fattening phase are the major contributor to EP. Manure management had only a low impact in all three studied systems. Alig et al. (2012) found a 36% higher EP for organic farms compared with conventional farms, whereas Presumido et al. (2018) observed a lower value of EP in an extensive system than in a semi-intensive system. These differences are most probably due to the different systems of beef cattle farming in the European countries. The comparison of roughage-based systems and concentrate-based systems carried out by three recent studies resulted in contradictory outcomes, just as for AP: on the one hand, Nguyen et al. (2010) and Pelletier et al. (2010) found that EP was lower for concentrate-based systems, while on the other hand, Lupo et al. (2013) found that it was lower for roughage-based systems. Lupo et al. (2013) argued that the lower EP in roughage-based systems could be explained by the lower dry matter feed intake and the lower amount of manure produced per kg live weight. However, there are only a few studies dealing with this topic and the results should therefore be interpreted with caution. It is also important to consider that several authors (e.g. de Vries et al., 2015; Dick et al., 2015) underline that AP and EP values strongly depend on the local climatic conditions and soil typology, and therefore, comparisons between studies are generally difficult. The main pollutant involved in EP was phosphate in water for all studied systems followed by nitrogen oxides in air (Appendix S4). The contribute of, phosphate in water plus nitrogen oxides in air, to the overall impact of EP ranges from 43% (CCF) to 62.8% (SCF).

Table 4
Percentage of the different processes involved on the impact of eutrophication potential in the different beef production systems.

%	CCF (n = 6)	SCF (n = 6)	HOF (n = 6)	S.E.M.
Concentrate production	70.3^a	36.0^b	58.6^b	7.2
Permanent grassland	26.7^b	54.9^a	34.6^b	8.6
Manure management	1.2	1.1	2.1	1.0

CCF: calf-fattening farms; SCF: suckler cow farms; HOF: heifer/ox fattening farms.
ab, $P < 0.05$; ac, $P < 0.01$; bc $P < 0.01$.
Cut-off 0.1%.

3.2.4. Non-renewable energy (NRE)

Non-renewable energy use in terms of MJ-eq was significantly higher for CCF farms compared with SCF and HOF farms (Fig. 5). Nguyen et al. (2010) found values ranging from 41 to 59 MJ-eq per kg live weight, which nearly corresponds to the value calculated for the CCF system in our study. The lower NRE use in SCF and HOF system can be explained by the use of more local and unprocessed feed products (especially hay and pasture grass) and the absence of artificial fertiliser. Williams et al. (2006) and Alig et al. (2012) found similar results for organic production systems. The CCF system in our study used milk replacer for calf feeding, which represents a highly processed feed that consumes a considerable amount of energy during its production. Hence, concentrate production had the highest impact on NRE use for the CCF system, while in the SCF and HOF system the permanent grassland influenced NRE use the most (Table 5). Several studies (e.g. Pelletier et al., 2010, Capper, 2012) demonstrated that concentrate-based systems had a lower energy-use than roughage-based systems, mainly due to an intensive grassland management (cutting, harvesting, conservation of forage, use of fertilisers etc.). However, the studied South Tyrolean farms correspond to more extensively managed roughage-based system and are therefore not perfectly comparable to the above-mentioned studies. Due to the extensive grassland management, the pasture-based systems SCF and HOF showed lower total use of NRE. General consumption was low for all production systems, showing no significant differences between them. This was mainly due to the relatively small size of all studied farms. The main pollutant was crude oil with almost 80% of impact in all systems (Appendix S5), while natural gas and coal had only a minor impact on the total use of NRE. This was most likely due to the low use of electricity and the lower use of fossil fuels for heating. A recent study conducted by Maia et al. (2020) observed that photovoltaic panels used as a roofing of the barns or as housings on pastures could reduce the use of NRE and thus further decrease the environmental impact of livestock farming systems.

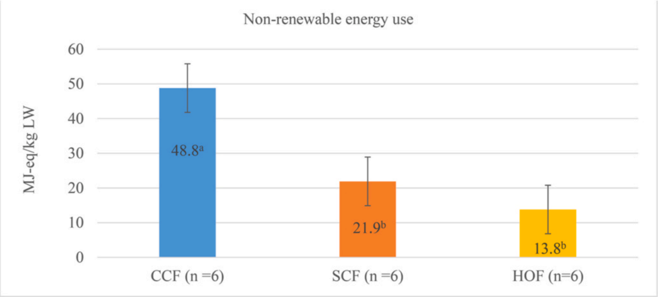

Fig. 5. Non-renewable energy use in the three different beef production systems per 1 kg live weight (LW), (means ± S.E.M.).

Table 5

Percentage of the different processes involved on the impact of non-renewable energy use in the different beef production systems.

%	CCF (n = 6)	SCF (n = 6)	HOF (n = 6)	S.E.M.
Concentrate production	55.5^{a}	29.8^{b}	46.3^{a}	4.9
Permanent grassland	41.4	66.1	51.0	9.3
General consumption	0.9	0.5	0.6	0.1

CCF: calf-fattening farms; SCF: suckler cow farms; HOF: heifer ox fattening farms.

ab, $P < 0.05$; ac, $P < 0.01$.

Cut-off 0.1%.

3.2.5. *Land occupation (LO)*

Land occupation refers to the area of land that is used for animal production and therefore is temporarily unavailable for other purposes (Nguyen et al., 2010). In terms of land occupation, significant differences were observed between the three systems (Fig. 6). CCF farms showed the highest values for land occupation with 127 m^2/year, followed by SCF farms and HOF farms with the lowest values among the three systems. The organic system showed a significantly higher value compared to the conventional system (70.8 vs 44.1 m^2/y; $P < 0.01$ respectively). Similar results were obtained by Dick et al. (2015) where the extensive system had the greatest impact on land occupation. Nguyen et al. (2010) showed that suckler-based systems had significantly higher land occupation than dairy-based ones due to the use of low productive grassland. In addition to that, Alig et al. (2012) found a higher land use in organic systems due to the lower grass yields and the lower growth rates of animals. Concentrate production was only a minor impact factor for land occupation, while permanent grassland had an influence of more than 90% for all three systems (Table 6). The SCF system showed the highest impact value with more than 97% of influence for permanent grassland. In the study area South Tyrol, most permanent grasslands would have no other use, i.e. these areas are not suitable for cereal or vegetable cultivation. Therefore, their degree of competition with human nutrition is very low. The latter is another important aspect, which should be considered while evaluating the sustainability of different animal production systems (Bragaglio et al., 2018).

3.3. *Biodiversity implications*

Table 6

Percentage of the different processes involved on the impact land occupation in the different beef production systems.

%	CCF (n = 6)	SCF (n = 6)	HOF (n = 6)	S.E.M.
Permanent grassland	94.1^{a}	97.2^{b}	94.4^{a}	2.1
Concentrate production	5.6^{a}	1.8^{b}	4.6^{a}	1.2

CCF: calf-fattening farms; SCF: suckler cow farms; HOF: heifer/ox fattening farms.

ab, $P < 0.05$.

Cut-off 0.1%.

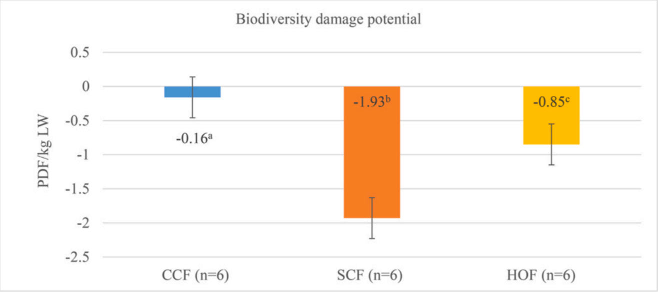

Fig. 7. Biodiversity damage potential in the three different beef production systems per 1 kg live weight (LW), (means ± S.E.M.).

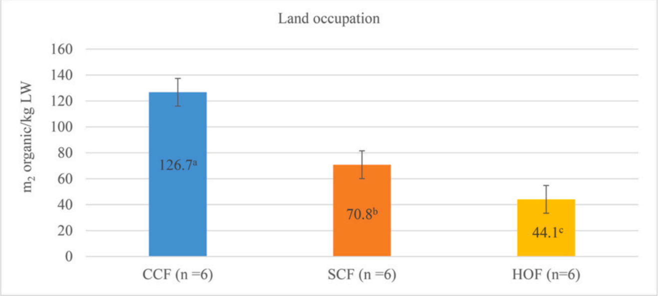

Fig. 6. Land occupation in the three different beef production systems per 1 kg live weight (LW), (means ± S.E.M.).

The assessment of the effect on biodiversity per 1 kg of LW was estimated using the approach suggested by Knudsen et al. (2017) using CFs. The organic SCF system showed the greatest benefits on biodiversity (−1.93 PDF/kg LW) compared to conventional CCF and HOF systems (−0.16, −0.85 PDF/kg LW respectively) (Fig. 7). The positive effects observed in our study were most likely due to the low use of concentrates and an increased use of the grazing resource, where a CF for land use type was −0.23, −0.36 for conventional and organic, respectively. Recent studies observed that a lower import of concentrated feed can promote biodiversity (Kok et al., 2020). Furthermore, the non-use of inorganic fertilizers such as phosphorus, potassium and nitrogen have a positive effect on biodiversity. The CCF system showed a value of −0.16 PDF/kg LW, which is significantly higher than in the other two systems. This is due to an increased use of concentrates and a total absence of grazing resource use. However, also the CCF system showed a positive overall effect on biodiversity. The conventional HOF system showed a positive performance in terms of effect on biodiversity (−0.85 PDF/kg LW), too. It was significantly better than the conventional CCF system ($P < 0.01$), most likely due to the different production performance in terms of kg LW, and also due to a great use of pasture resource (95 days per year). Compared to the organic system, the HOF system was significantly more impactful in terms of BDP (−0.85 vs −1.93 PDF/kg LW, HOF and SCF, respectively). This was likely due to a greater use of concentrated feed and a lower extension of the grassland area (Table 1). The organic SCF system was significantly more biodiversity-friendly than the two conventional systems ($P < 0.01$). However, so far this approach has only been applied to the dairy cow sector (Guerci et al., 2013; Battini et al., 2014; Sabia et al., 2020b). Knudsen et al. (2019) observed a negative value for BDP in an organic system of dairy cows kept in mountain areas. Battini et al. (2014) observed positive results per kg of milk, thus with a greater impact in terms of damage to biodiversity. Grazing animals have a positive effect on the plant species due to the distribution of feces on the land and also by enriching the soil with organic matter (Gillet et al., 2010). The animals exert a mechanical action of compaction of the soil through their trekking action, which prevents erosion (Eichberg and Donath, 2018). However, some authors indicate that pasturing on areas with high plant biodiversity has a negative effect on the growth performance of beef cattle compared to grazing on cultivated areas (Fraser et al., 2009). In the Alpine system, grazing animals can be considered an integral part of the biodiversity of a system. The abandonment of grassland and pastures leads to a reduction of plant and animal biodiversity (Scotti et al., 2020). The CFs is one approach used so far to estimate and assess the impact and effect of the livestock sector on biodiversity (Guerci et al., 2013; Knudsen et al., 2019; Sabia et al., 2020b). However, it is a rather general approach and it is necessary to carry out direct studies in individual ecological areas in order to observe the many variables that affect an ecological system and its biodiversity.

4. Conclusion

The study showed that meat production in the mountainous area South Tyrol is largely carried out under extensive conditions and therefore has a satisfactory environmental performance. The limited use of concentrate feed and the non-use of artificial fertilizers and herbicides contribute to a sustainable production. When comparing conventional and organic production methods of the present study, the positive effect of organic farming on biodiversity can be highlighted. The comparison between production systems showed that veal production in South Tyrol has the highest negative impact on the environment, while suckler cow husbandry and heifer/ox fattening have only a low negative environmental impact, especially if compared with other European countries. The results of our study may be useful to find practical measures to improve environmental performance, for example by reinforcing pasturing and focusing on sustainable feeding strategies using only farm-own feed. However, more studies are needed to better assess the effect on biodiversity of livestock production such as beef cattle breeding.

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.

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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.2021.112523.

Credit author statement

Verena Angerer: Conceptualization, Methodology, Formal analysis, Validation, Visualization, Writing – original draft, Writing review & editing. Emilio Sabia: Conceptualization, Methodology, Formal analysis, Validation, Visualization, Writing, Writing – original draft, Writing review & editing, Data curation, Supervision. Uta König von Borstel: Supervision, Review. Matthias Gauly: Conceptualization, Methodology, Formal analysis, Validation, Visualization, Writing, Writing – original draft, Writing review & editing, Data curation, Supervision.

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