

Article

Environmental Impacts of Beef as Corrected for the Provision of Ecosystem Services

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Abstract: We aimed to assess whether the environmental impacts in terms of global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and land occupation (LO) of beef can be decreased when ecosystem and cultural/provisioning services are included in the evaluation. We used four Italian production systems: Fat, with beef imported calves kept in confinement; CoCaI, with beef cows and calves kept in confinement; SpEx, with beef cows and calves kept on pasture and finishing conducted in confinement; and Pod, with Podolian cows and calves kept on pasture and finishing conducted in confinement. After the economic allocation, the GWP of system Pod decreased considerably and showed values lower than those computed for systems CoCaI and SpEx ($P < 0.05$ and $P < 0.001$, respectively). System Pod showed the lowest AP and EP as compared with all the other systems ($P < 0.01$). Systems Fat and CoCaI showed the smallest LO, with values lower than systems Pod ($P < 0.05$) and SpEx ($P < 0.001$). We conclude that the environmental impacts of extensive and local beef production systems in terms of GWP, AP, and EP was markedly reduced when the provision of accessory services was included in the calculation. Conversely, LO did not markedly change due to the high absolute values needed to allow pasture-based feeding. The estimation of additional positive aspects linked to the use of natural pastures, such as removal of carbon dioxide, increased biodiversity, and exploitation of feeds nonedible by humans, may allow a further reduction of LO.

Keywords: beef cattle; Podolian breed; life cycle assessment; ecosystem services; environmental impact

1. Introduction

Beef is an important protein source for human diet, particularly in industrialized countries [1]. In addition, there is an increasing pressure on the livestock sector to meet the growing demand for high-value animal protein mainly coming from developing countries, with an expected increase of 74% by 2050 [1,2]. Livestock farming systems (LFS) differ widely in terms of use of resources, degree of intensification, species and orientation of production, local/regional socio-economic and market context, cultural roles, etc. Henle et al. [3] suggested that pasture-based livestock farming systems play a central role in the management and conservation of large high nature value farmland in Europe, mainly in the Mediterranean basin countries. However, important changes have occurred during the last half of the 20th century, due to the modernization and intensification of agriculture and the establishment of new economic and commercial relationships with urban areas, which have caused depopulation and a continuous reduction or abandonment of livestock farming in rural areas across Europe [4,5]. Therefore, the number of agricultural holdings with grazing livestock in Mediterranean Countries has declined sharply in the recent years [6]. However, livestock production and beef production in

particular, are charged with having a large impact on the environment in terms of greenhouse gas (GHG) emissions (beef accounts for 6% of the global GHG emissions according to Gerber et al. [7]) land degradation and deforestation [8], and terrestrial acidification and eutrophication [9]. Environmental impacts per kg of edible beef [10] vary largely (from 14 to 32 kg CO₂ equivalents for GHG emissions and from 27 to 49 m² year⁻¹ for land use) due to differences in methodological choices and differences in beef production systems. In several western countries, including Italy, systems based on confined more specialized animals are combined with grazing systems based either on local or specialized breeds in a mixed production scenario. From an environmental perspective, the identification of beef production best practices is not simple, as different systems may imply trade-offs between different forms of impact: some systems may sustain biodiversity and promote carbon sequestration, others may be more efficient in terms of feed conversion ratios [11]. Numerous authors showed that intensive systems had lower global warming potential (GWP) and land occupation (LO) values than, for instance, systems partially based on pasture [12–14]. Similarly, in a previous study [14] on the most common beef production systems used in Italy, although no significant effect of production system on water depletion (WD) was observed, intensive systems showed lower GWP and LO. However, these results do not take into account that, besides beef production, grass-based systems may provide other services, such as preservation and enhancement of biodiversity [3], conservation of cultural landscapes [15], contribution to the socio-economic viability of many rural and marginal areas [16], and enhancement of meat quality and animal welfare levels, as perceived by consumers [17]). Therefore, the outputs of life cycle assessment (LCA) should include not only material products but also other non-commodity outputs and non-marketable goods, named “ecosystem services” [18] and related to the multifunctional role of livestock [19]. The ecosystem functions have been defined as ‘the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly’ [20]. One way to estimate the role played by these goods and correct the emissions accordingly is the economic allocation. Despite the debate about allocation, particularly about economic allocation, in agreement with previous studies [21,22], we chose this method as a means to correct farm emissions. Several authors aiming to quantify the value of by-products [23,24] and “externalities” [25] used the economic allocation in ruminants. Moreover, economic partitioning is also frequently applied to fisheries and aquaculture [26].

Livestock enterprises often produce multiple-outputs [6,22], such as milk and/or meat, but also cereals, hay, and several by-products (e.g., manure, skin, wool, and straw). Additionally, pasture-based livestock systems produce positive externalities or public goods such as landscape conservation [15,27], biodiversity enhancement [14,28], and wildfire prevention [19,29]. Despite the fact that these services are often difficult to measure, according to the LCA method, these externalities can be considered as co-products to which an economic value can be assigned. Even non-market goods can be estimated using different methods, including the travel cost method (TCM), which is considered a proxy of the visitor’s willingness to pay for particular places or to attend specific events [30,31]).

Therefore, following up on the study conducted by Bragaglio et al. [14] on the environmental impact of the main Italian beef production systems, we aimed to compare four beef-production systems in terms of global warming potential, acidification potential, eutrophication potential, and land occupation, before and after the economic allocation of the ecosystem service, such as preservation of biodiversity, conservation of landscapes, contribution to the socio-economic viability of many rural areas, and co-products (e.g., milk production and transformation) provided by each system.

2. Materials and Methods

The present study is based on life cycle assessment (LCA) [32]. Four different phases are envisaged: goal and scope definition, inventory analysis, assessment of the impact, and data interpretation [33,34].

2.1. Goal and Scope Definition

The goal of our study was to compare four beef-production systems in terms of global warming potential (GWP, kg CO₂-eq), acidification potential (AP, kg SO₂-eq), eutrophication potential (EP, g NO₃-eq), and land occupation (LO, m₂ year⁻¹) before and after the economic allocation of the ecosystem services and co-products provided by each system. One kg of live body weight of beef was the functional unit.

2.2. System Boundaries

A cradle-to-farm gate approach was used, as also shown by the system boundaries of the four beef-production systems reported in Figure 1. We included in the study all on-farm activities (such as management of animals and manure, use of energy, and production of feeds) and the corresponding emissions under the form of primary data. Emissions and consumptions from off-farm activities (i.e., production of bedding materials, feeds, pesticides and fertilizers; transport of calves, feeds, and bedding material) were obtained from Simapro 8.01 databases. In particular, we used Agri-footprint for raw materials (barley, maize, and soybean), fertilizers (urea and phosphates) and energy sources (heavy fuel oil); U.S. Life Cycle Inventory for energy sources (diesel and residual fuel oil) and transport vehicles (ocean freighter); Ecoinvent for raw materials (wheat grain; fava bean feed; tap water) energy sources (electricity) and transport vehicles (lorries, tractors) and facilities.

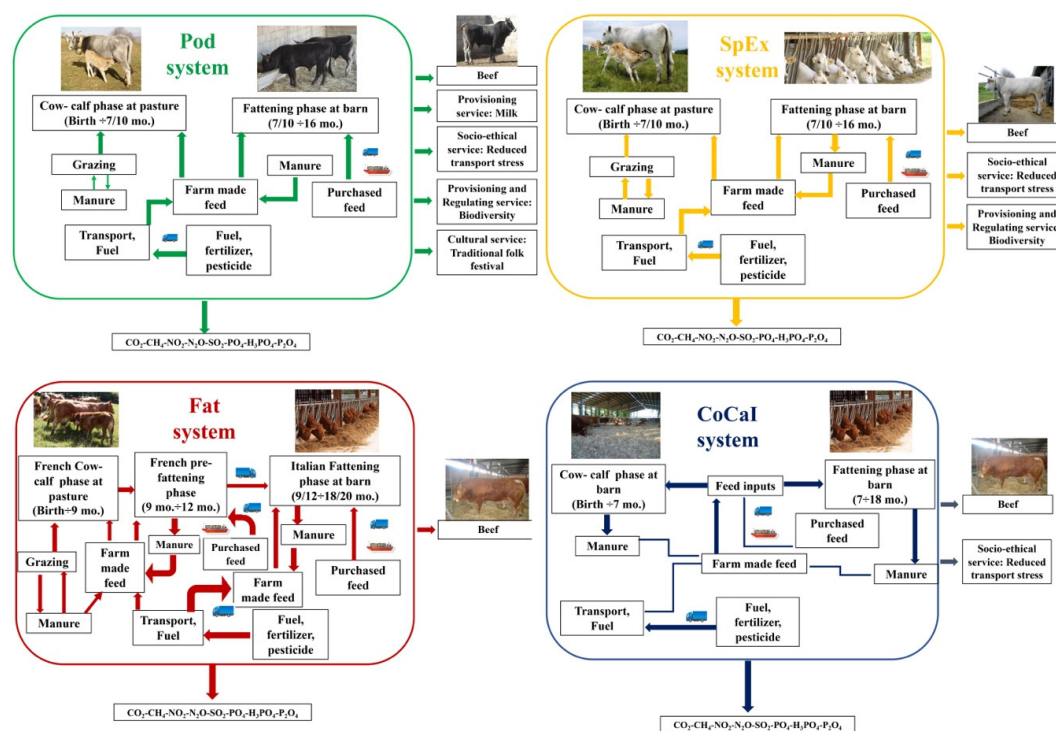


Figure 1. System boundaries of the four beef-production systems. Pod: Podolian System; SpEx: Specialized Extensive; CoCaI: Cow Calf Intensive; Fat: Fattening System.

2.3. Inventory Analysis

Twenty-five beef farms were used. Six farms had specialized beef breed imported calves fed with concentrate based diets (Fat); five farms had specialized beef breeds with cows and calves constantly kept in confinement (CoCaI); seven farms had specialized beef breeds, they maintained cows and calves on pasture in the first phase and then finished beef animals in confinement (SpEx); seven farms had the local Podolian cattle breed, they maintained cows and calves on pasture in the first phase and then finished beef animals in confinement (Pod). The main characteristics of these four farming systems and the corresponding diets are reported in Tables 1 and 2, respectively.

Table 1. Main characteristics of the four beef production systems (means \pm SD).

	Podolian System (Pod)	Specialized Extensive (SpEx)	Cow Calf Intensive (CoCaI)	Fattening System (Fat)
Breed	Native (Podolian cattle)	Specialized	Specialized	Specialized
Farm extension, ha	310 \pm 232	221 \pm 204	34.00 \pm 20.00	77.00 \pm 12.00
Arable, ha	30.70 \pm 36.80	59.30 \pm 53.40	34.00 \pm 20.00	77.00 \pm 12.00
Pasture, ha	279.30 \pm 221.00	167.30 \pm 191.60	-	-
Pasture and meadow, ha	177.00 \pm 189.40	80.00 \pm 65.60	-	-
Shrub land, ha	120.00 \pm 56.60	35.00 \pm 7.10	-	-
Forest, ha	166.00 \pm 168.30	175.30 \pm 161.60	-	-
Production system	Cow-calf suckling/grazing + indoor fattening/grain-based diet	Cow-calf suckling/grazing + indoor fattening/grain-based diet	Cow-calf suckling indoors + indoor fattening/high-grain-based diet	Indoor fattening of imported calves/high-grain-based diet
Pre-fattening age, d	184.28 \pm 32.07	192.86 \pm 16.03	198.00 \pm 26.83	360.83 \pm 56.98
Pre-fattening weight, kg	194.29 \pm 16.94	210.71 \pm 37.46	264.00 \pm 26.08	378.33 \pm 70.54
Daily weight gain, kg	1.09 \pm 0.12	1.23 \pm 0.15	1.29 \pm 0.11	1.34 \pm 0.26
Fattening time, d	305 \pm 41.53	305 \pm 45.00	327 \pm 56.00	241 \pm 87.00
Slaughter age, d	489.28 \pm 58.34	489.28 \pm 49.03	525.00 \pm 41.98	581.67 \pm 83.36
Slaughter weight, kg	521.43 \pm 26.88	575.00 \pm 77.73	682.00 \pm 40.87	679.17 \pm 81.02

Table 2. Components and composition of the feeding rations used in four beef production systems.

	Pod	SpEx	CoCaI	Fat
Feed for cow-calf period (kg/head/day)				
Pastured grass	44.00	44.00	-	44.50 ^a
Meadow hay	0.26	1.61	3.43	12.64 ^b
Maize silage	3	-	13.18	-
Sorghum silage	-	-	1.09	-
Maize flour	-	-	0.75	-
Barley	-	-	-	1.60 ^b
Wheat	-	-	-	1.44 ^b
Straw	1.13	0.86	0.80	-

Table 2. Cont.

	Pod	SpEx	CoCaI	Fat
Chemical composition (%)				
Dry matter (DM)	14.25	15.21	8.60	8.90 ^a 14.80 ^b
Crude protein (% DM)	7.78	7.83	7.91	10.00 ^a 12.90 ^b
Neutral detergent fiber (% DM)	55.55	56.00	55.11	55.00 ^a 43.70 ^b
Ether extract (%)	1.17	1.33	3.80	1.70 ^a 1.00 ^b
Ash	7.14	7.29	7.22	9.00 ^a 8.30 ^b
MFU	0.63	0.62	0.67	0.79 ^a 0.71 ^b
Supplementation for Fat calves in cow-calf period (198–274 d) (kg/head/day)				
Barley				0.26
Wheat				0.60
Soybean meal				0.08
Rape seed meal				0.10
Sunflower meal				0.08
Chemical composition (%)				
Dry matter (DM)				0.98
Crude protein (% DM)				18.70
Neutral detergent fiber (% DM)				23.70
Ether extract (% DM)				3.60
Ash				3.54
MFU				1.12
Feed for Fat calves in pre –fattening period (275–360 d) (kg/head/day) (kg/head/day) (kg/head/day)				
(kg/head/day) (kg/head/day)				
Meadow hay				3.00
Barley				1.60
Wheat				1.60
Soybean meal				0.25
Rape seed flour				0.14
Maize flour				0.46

Table 2. Cont.

	Pod	SpEx	CoCaI	Fat
Chemical composition (%)				
Dry matter (DM)				6.25
Crude protein (% DM)				12.7
Neutral detergent fiber (% DM)				40.40
Ether extract (% DM)				4.13
Ash				6.20
MFU				0.90
Feed for bull –fattening period (kg/head/day)				
Barley	0.88	3.43	0.82	-
Oat	0.42	0.50	-	-
Wheat	0.59	0.49	-	-
Field bean (<i>Vicia faba minor</i>)	0.24	1.30	0.13	-
Meadow hay	0.59	1.78	2.11	1.13
Straw	1.48	3.12	1.58	1.23
Wheat flour shorts	0.89	0.40	0.32	1.71
Maize flour	1.81	1.81	2.26	3.05
Bran	0.04	0.55	0.33	1.81
Sunflower meal	0.40	0.15	0.29	0.04
Maize silage	-	-	13.16	6.94
Triticale silage	-	-	-	0.61
Palm oil	-	-	0.02	0.15
Brewers grains	-	-	-	0.67
Soybean hulls	-	-	0.20	-
Corn grits	-	-	0.20	-
Cob of corn	-	-	0.08	-
Distillers grain	-	-	0.06	-
Dry matter (DM)	6.61	12.36	11.68	10.36
Crude protein (% DM)	12.19	12.39	15.02	12.61
Neutral detergent fiber (% DM)	33.71	36.77	40.43	37.96
Ether extract (% DM)	3.08	2.93	3.23	4.62
Ash	4.47	5.29	6.18	5.29
MFU	0.93	0.86	0.85	0.92

Pod: Podolian System; SpEx: Specialized Extensive; CoCaI: Cow Calf Intensive; Fat: Fattening System; a: grazing period of 228 d; b: cow housing period of 46 d; MFU—meat forage unit.

2.4. Emissions

Enteric emissions, emissions urine and faeces produced while grazing, emissions from manure, emissions due to chemical fertilization and fuel combustion were used to estimate total on-farm emissions. In particular, the Intergovernmental Panel Climate Change (IPCC) [35,36] methodology based on the relationship between gross energy intake and emissions was used. Following the indications from the IPCC, the Equation 10.16 was used to assess the gross energy intake, while the emissions were assessed with the equations given below:

- 10.21 to assess CH₄ emission factors for enteric fermentation from a livestock category (Tier 2)
- 10.23 to assess CH₄ emissions factor from manure management (Tier 2)
- 10.24 to assess volatile solid excretion rates (VS) considered in equation 10.23 (Tier 2)
- 10.25 to assess direct N₂O emissions from manure management (Tier 1)
- 10.26 to assess N losses due to volatilization from manure management (Tier 1), useful for equation 10.27
- 10.27 to assess indirect N₂O emissions due to volatilization of N from manure management (Tier 1)
- 10.28 to assess N losses due to leaching from manure management (Tier 2), useful for equation 10.29
- 10.29 to assess indirect N₂O emissions due to leaching from manure management (Tier 2)
- NH₃ emissions are assessed by multiplying data provided by equations 10.26 and 10.28 by specific ratio 17/14
- 10.31 to assess annual N excretion rates (Tier 2)
- 10.32 to assess N intake rates for cattle (Tier 2)

More details on data acquisition and equations are reported by Bragaglio et al. [14].

2.5. Impact Assessment

The LCA methodology (SimaPro 8.01 PhD, PRé Consultants, 2013) was applied to assess the acidification potential (AP, g SO₂-eq), global warming potential (GWP, kg CO₂-eq), eutrophication potential (EP, g NO₃-eq), and land occupation (LO, m₂). In particular, the evaluation of AP, GWP, and LO relied on the ReCiPe Midpoint (I) module of SimaPro, whereas EP was evaluated using the method Edip LCA Food, as it comprises both marine and fresh water, and is expressed in terms of NO₃ eq. The GWP was computed on the basis of the CO₂-equivalent factors, as defined by the IPCC (2007) (CO₂ = 1; CH₄ = 25; N₂O = 298) and a 100-year time span. The AP was estimated by using the SO₂-equivalent factors (NO₂ and NO_x = 0.7; SO₂ and SO_x = 1; NH₃ = 1.88), as suggested by Heijungs et al. [37], whereas the EP was calculated by using the PO_x-equivalent factors (NO₃ = 0.1, NO₂ and NO_x = 0.13; NH₃ = 0.33; P = 3.06), as suggested by Heijungs et al. [38].

2.6. Evaluation of the Ecosystem Services and Economic Allocation

In order to perform an economic allocation between the multiple outputs of the four systems, all products were economically evaluated.

The economic value from beef production was calculated by multiplying the number of cattle sold per year by the average live weight by the average price at farm gate. Marketed beef cattle included culled cows (0.45 €/kg live weight considered for Pod, SpEx, and CoCaI as indicated in the Commodity Exchange of Perugia, 2014) and young bulls or heifers, 2.38, 2.72, 2.98, and 2.70 €/kg for Pod, SpEx, CoCaI, and Fat respectively, retrieved by interviews to the farmers in the same period. The amount of culled cattle with marketed beef constitutes the “farm income”.

Common Agricultural Policy includes payments (202 €/head) assigned to each calf, born in Italy from and suckled by beef cows. This subsidy can be assimilated to social-ethical services, such as the reduced stress of calves which are not transported over long distances from abroad [39]. Additional payments, which can sum up to 242.40 €/head, are given by the National Breeder Association of Italian Beef Cattle (ANABIC) to the associated farmers. In this case, the associated ecosystem services include

the protection of biodiversity in terms of local beef breed conservation and regulating services related to their ability to ingest and digest high fiber fodder in upland natural pastures [19,37]. Obviously, Fat is excluded by both suckler cow and ANABIC subsidies.

Thus, the redistributed amount of “no-beef income” due to subsidies and the economic value usable to subtract the corresponding on-farm pollutants, was computed as follows:

$$Av\text{€} = p(x, y, z) * nd / \sum(ncc, nmb) * bw \quad (1)$$

where:

Av € is the animal value, in euros, related to 1 kg of live weight of marketed cattle in terms of subsidies;

p is the payment of € $x = 0$, $y = 202.00$, $z = 242.40$ for the dams involved;

nd is the number of dams involved;

ncc is the number of culled cows;

nmb is the number of marketed beef (young bulls and heifers);

bw is the body weight.

In addition to the payments of subsidies, for the system Pod the “no beef income” may also include the income from milk production and the corresponding ecosystem services. In particular, the milk of Podolian cows and the transformed dairy products (mainly represented by “Caciocavallo” cheese) can be considered as co-products for the distribution of pollutants. These products are obtained through the application of traditional, ancient and local practices which have been passed down through generations [40]. The production of milk, can be, therefore, considered as both a provisioning service (production of milk and dairy products) and a cultural service (conservation of traditional, ancient, and local practices) [7]. Despite its good technological characteristics (3.5% protein, 4.4% fat, and 4.5% lactose; [41], an average price at shed of 0.3975 €/kg was estimated. This price was obtained by the monthly mean of the years 2014, 2015, and 2016 of the Puglia region [42], and approximated to 0.40 €/kg. Thus, the redistributed amount of “no-beef income” due to milk production, was computed as follows:

$$Mt\text{€} = mp * ma * nd / \sum(ncc, nmb) * bw \quad (2)$$

where:

Mtv € is the total value in euros of the milk produced in one year related to 1 kg of live weight of marketed cattle;

mp is the current value of “high quality milk” at shed (i.e., 0.40 €/kg);

ma is the total amount of milked milk in kg produced by one cow in one year;

nd is the number of lactating dams;

ncc is the number of culled cows;

nmb is the number of marketed beef (young bulls and heifers);

bw is the body weight.

We used the expenses incurred by the interviewed tourists to attend the event as a proxy of their willingness to pay for cultural services. In particular, we adapted the travel cost method (TCM) reported by Ezebilo [43] to the system Pod, by assessing, through a questionnaire, the attractiveness of “Maggio di Accettura”, a traditional festival held in May every year in a small town (Accettura, MT) located in Basilicata (Italy), where the Podolian cattle play a central role. This festival, is a “four-day Pagan fertility ritual” that has survived over the centuries, where two trees, the “Maggio” a tall old oak, and the “Cima”, a holly tree, are cut from the forests surrounding Accettura, to be transported into town. The Maggio is pulled by one-hundred Podolian steers, while the “Cima” is carried on shoulder by the town’s young men for over 20 km to the main square, where they are joined in a symbolic wedding ceremony.

A trained interviewer verbally informed the interviewed tourists about the scope of the study and the questionnaire construction. The questionnaire consisted of two questions:

- (a) place of departure;
- (b) importance of Podolian cattle as a reason for their travel, evaluated using a 10-point scale from 0 (completely irrelevant) to 10 (the sole reason).

Although the festival is a four-day event, we conducted the estimation by considering only the day in which the Podolian cattle were the main attraction. Data from 85 people were collected, and the distance covered was calculated. All the people used a car to get to the site, apart from few respondents coming from Great Britain and taking a ferryboat in addition to a car. We calculated with “Via Michelin Percorsi” [44] the expenses of the car travel, assuming a diesel engine car for all the respondents; the motorway toll was also included in the calculation. We corrected this value using the second question of the questionnaire in order to take into account the interest expressed by the travelers towards the Podolian breed (expense * relevance/10). Then, we calculated the mean corrected expenses of the 85 interviewees and assigned it to each animal reared in each farm of the system Pod. Subsequently, we distributed this value to beef as indicated below:

$$Cv\text{€} = wp * nh / \sum(ncc, nmb) * bw \quad (3)$$

where:

$Cv\text{€}$ is the cost value related to 1 kg of live weight of marketed cattle as “cultural attraction”;

wp is the willingness to pay, estimated as 33.21 €;

nh is the total number of animals in each PoS farm;

ncc is the number of culled cows;

nmb is the number of marketed beef (young bulls and heifers);

bw is the body weight.

2.7. Statistical Analyses

We used ANOVA to assess the effects of the production system (Fat, CoCaI, SpEx, and Pod), allocation (before and after the economic allocation of the ecosystem services) and interaction production system \times allocation on GWP, AP, EP, and LO. In particular, we applied the general linear model procedure of the software SAS (SAS Institute Inc., Cary, NC, USA).

3. Results and Discussion

3.1. Economical Allocation

The systems CoCaI and Fat showed the highest farm income (2.70 €/kg from beef and culled cows), followed by SpEx (2.31 €/kg), and Pod (2.07 €/kg). However, when the subsidies were considered, the incomes including the payments were 2.92 €/kg, 2.65 €/kg, and 2.58 €/kg for CoCaI, Pod, and SpEx, respectively, whereas the income of Fat remained unchanged (2.70 €/kg). Therefore, Pod showed the highest percent of income from subsidies (21.6%), followed by SpEx (9.7%), CoCaI (7.2%), and Fat (0.0%). The intensive systems (i.e. Fat and CoCaI) were penalized because they only kept the breeds Charolaise and Limousine. Therefore, they were excluded from the payments for Italian beef cattle breeds. In the system SpEx, 1 out of 7 farms kept Italian beef cattle, thus receiving both the payment for suckler cows and the payment for biodiversity, whereas 3 out of 7 farmers received the payment for suckler cows, but did not adhere to the ANABIC scheme, thus not receiving the payment related to biodiversity even if they kept Italian beef cattle, 2 out of 7 received the payment for suckler cows, but did not keep Italian breeds, thus not receiving the payment related to biodiversity, and 1 out of 7 neglected the suckler cow subsidy and did not keep Italian breeds, thus receiving no payments. Conversely, all of the farms from the system Pod received the payment for suckler cows and five out of seven obtained the payment

related to biodiversity. However, the percent value attributed to subsidies decreased to 15.7% when the income from milk and the willingness to pay to attend a local traditional festival were considered. As to the evaluation of the cultural services associated with this local traditional festival, all the respondents showed a very high interest for the presence of the Podolian cattle (mean score \pm SD = 9.34 ± 1.25), and a corresponding mean economic value of 33.21 €/head was obtained for this externality. Table 3 shows the impacts of the four farming systems before and after the economic allocation.

3.2. Global Warming Potential

GWP was significantly affected by the production system and the allocation ($P < 0.01$). The interaction allocation \times production system was also significant ($P < 0.01$). In agreement with previous studies, which showed that the intensification of animal production could mitigate certain environmental impacts, such as the emission of greenhouse gases [12], in our experiment, the most intensive system (i.e., Fat) showed lower GWP values than systems partially based on pasture (Table 3), such as Pod and SpEx ($P < 0.01$). In these latter systems, enteric emissions represented the main source of greenhouse gases due to the high amount of forage included in the diet, whereas in intensive systems such as Fat, where a high amount of fat silage is used, feeding plays a major role [45]. Feeding based on maize silage is generally rather impactful, because the cultivation requires high amounts of inorganic and organic fertilizers and water. Conversely, no differences were observed between the two intensive systems (Fat and CoCaI) and the two extensive systems (Pod and SpEx). However, the GWP of system Pod decreased considerably when the provision of the ecosystem services was considered in addition to the production of meat (Table 3), and showed values lower than those computed for systems CoCaI and SpEx ($P < 0.05$ and $P < 0.001$, respectively). In addition, after the economic allocation, although GWP was still higher in system SpEx as compared with system Fat ($P < 0.05$), no significant differences were observed between systems Pod and Fat. These latter results may be attributed to the fact that the farms from the system SpEx only benefited from the detraction due to the ecosystem services related to the suckler cow subsidy (social–ethical service), whereas the farms from the system Pod also provided milk (provisioning services), the ecosystem services related to biodiversity conservation, and the cultural services associated with a local traditional festival.

3.3. Acidification Potential

AP was significantly affected by the production system and the allocation ($P < 0.001$). The interaction allocation \times production system was also significant ($P < 0.05$). Without economic allocation (Table 3), the highest value of AP was observed in system CoCaI as compared with the other three systems ($P < 0.001$). No other significant differences were observed between systems before the economic allocation. These results can be attributed to the higher amount of concentrated feeds used in the system CoCaI (i.e., concentrates and, partly, silages). Accordingly, Castanheria et al., [46] observed that a relevant source of emissions to air and water from cattle farming is the production of concentrates. In system CoCaI most of the impact can be attributed to manure emissions (42%), but feeding also had a high impact, both in the fattening (27%) and pre-fattening periods (26%). For the extensive systems Pod and SpEx, the percent impacts attributed to manure emissions were even higher (68% and 52%, respectively), whereas for the system Fat, the main source of acidification was represented by feeding in the pre-fattening and fattening periods (52% and 36%, respectively). In intensive systems, ammonia is one of the main sources of terrestrial acidification due to nutrient management and manure management [9]. When the allocation was considered, system Pod showed the lowest impact, as compared with all the other systems ($P < 0.001$), whereas systems SpEx and Fat had impacts lower than CoCaI ($P < 0.001$). As also observed for GWP, the economic allocation determined the highest reduction of the impact for system Pod, whereas a lower reduction concerned the system SpEx. Conversely, the economic allocation did not markedly change the AP of the system CoCaI, which, therefore, remained the most impactful (Table 3).

Table 3. Cradle-to-farm gate life cycle * global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and land occupation (LO) of four beef production systems before and after the economic allocation of the ecosystem services (mean \pm SE).

	Pod		SpEx		CoCaI		Fat		Significance		PS \times A
	Before Allocation	After Allocation	Before Allocation	After Allocation	Before Allocation	After Allocation	Before Allocation	After Allocation	Production System (PS)	Allocation (A)	
GWP, kg CO ₂ -eq	26.30 \pm 1.65	14.92 \pm 1.58	25.41 \pm 1.58	23.12 \pm 1.58	21.94 \pm 1.87	20.32 \pm 1.87	17.62 \pm 1.71	17.62 \pm 1.71	0.0029	0.0027	0.0049
AP, kg SO ₂ -eq	0.20 \pm 0.01	0.11 \pm 0.01	0.22 \pm 0.01	0.19 \pm 0.01	0.30 \pm 0.02	0.28 \pm 0.02	0.11 \pm 0.01	0.20 \pm 0.01	0.0001	0.0027	0.0211
EP, g NO ₃ -eq	961.7 \pm 60.5	546.8 \pm 60.5	1009.8 \pm 60.5	910.5 \pm 60.5	1009.2 \pm 60.5	937.7 \pm 71.6	779.2 \pm 65.4	779.2 \pm 71.6	0.0010	0.0026	0.0091
LO, m ² year ⁻¹	177.7 \pm 18.7	101.4 \pm 18.7	194.4 \pm 18.7	172.6 \pm 18.7	32.6 \pm 22.1	30.2 \pm 22.1	40.7 \pm 20.2	40.7 \pm 20.2	0.0001	0.0831	0.1882

* Functional unit: 1 kg of live weight; Pod: Podolian System; SpEx: Specialized Extensive system; CoCaI: Cow-calf Intensive system; Fat: Fattening system.

3.4. Eutrophication Potential

EP was significantly affected by the production system, and the allocation and the interaction allocation \times production system ($P < 0.001$). As reported in Table 3, system Fat showed lower impacts than systems CoCaI, SpEx, and Pod ($P < 0.05$). A relevant contribution to EP was given by feeding, in particular during the pre-fattening period (44%). Conversely, in system Fat, the main source of eutrophication was the emission originating from the feeding inputs during the fattening period (48%). While nitrates deriving from agricultural activities, including animal farming, represent the main source of water eutrophication [47], Dick et al. [48] observed that intensive farming systems generally show higher impacts in terms of EP, as compared with extensive systems. When the economic allocation was included in the estimation of the impact, system Pod showed the lowest EP, with significant differences, as compared with systems CoCaI ($P < 0.001$), SpEx ($P < 0.001$), and Fat ($P < 0.01$). Although the economic allocation did not change the impact of Fat, this system showed the second lowest impact in terms of EP. However, differences only tended to be significant in comparison with system CoCaI ($P < 0.10$). As observed for the previous impact categories, the economic allocation determined the highest reduction of EP in system Pod, while minor reductions were computed for systems CoCaI and SpEx.

3.5. Land Occupation

LO was significantly affected by the production system ($P < 0.001$), whereas the allocation only tended to affect LO ($P < 0.10$). The interaction allocation \times production system was not significant. Before allocation, significant differences were observed between the four systems, with Pod and SpEx showing higher values, as compared with CoCaI and Fat ($P < 0.001$). Farm extension was the main contributor of LO in systems Pod, SpEx, and CoCaI (64%, 62%, and 38%, respectively), while in the system Fat, LO was mostly influenced by feeding inputs during the pre-fattening phase conducted abroad. When the economic allocation was considered in the estimation of LO, systems Fat and CoCaI showed the smallest impacts with values lower than systems Pod ($P < 0.05$) and SpEx ($P < 0.001$) again. Due to the higher reductions in system Pod, a significant difference was also observed with system SpEx ($P < 0.05$) with a lower impact for the former. In the case of LO, the economic allocation was unable to markedly change the impacts of systems Pod and SpEx, due to the high absolute values of LO in the extensive systems where feeding is pasture-based, thus needing large grazing areas to cover animal feeding requirements, particularly in the case of low-quality natural grasslands. In general, concentrate-based farming systems show a lower LO impact per kg of product in comparison with roughage-based systems, due to the higher growth rate shown by the calves fed with concentrates [13]. In addition, grazing animals have higher maintenance requirement due to the higher energy expenditures related to exploration and walking, which in turn are needed for feed selection and ingestion [49,50]. Land use change from forest to cropland generally implies an increment of carbon dioxide in the atmosphere, thus increasing the GWP [51]. However, natural pastures, such as those used in systems Pod and SpEx, remove carbon dioxide from the atmosphere, and leave room for plant and animal biodiversity. In addition, in these systems, feeds nonedible by humans are used [52]. Conversely, the cereal-based beef cattle industry may increase the risk of water contamination due to the leaching of fertilizers in the areas where feeds are produced while consuming feeds which are also edible for humans [53].

4. Conclusions

One of the most significant findings to emerge from this study is that the environmental impact of some Italian beef production systems can be markedly reduced when the provision of accessory services was included in the calculation. The most significant reductions in terms of GWP, EP, and AP were estimated for the system Pod, which was able to provide the society with a high number of services. In particular, this system supplied social–ethical services, such as reduced transport stress, protection of biodiversity, such as conservation of a local ancient cattle breed, and cultural/provisioning services, such as milk production and transformation. Less significant reductions were estimated for

SpEx and CoCaI, whereas no reductions could be awarded to the system Fat, as no services in addition to the production of beef were identified. Conversely, in the case of LO, the economic allocation was unable to markedly change the impacts of the extensive systems (i.e., Pod and SpEx) due to the high absolute values needed to allow pasture-based feeding. However, natural pastures remove carbon dioxide from the atmosphere, leave room for additional plant and animal biodiversity, and rely on feeds nonedible by humans. The inclusion in the estimation of these latter positive aspects may allow a further reduction of the environmental impacts of systems Pod and SpEx.

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References

1. FAO. Livestock in the Balance. In *The State of Food and Agriculture*; FAO: Rome, Italy, 2009; ISBN 978-92-5-106215-9.
2. Alexandratos, N.; Bruinsma, J. *World Agriculture towards 2030/2050: The 2012 Revision*; ESA Working paper No 12-03; FAO: Rome, Italy, 2012.
3. Henle, K.; Alard, D.; Clitherow, J.; Cobb, P.; Firbank, L.; Kull, T.; McCracken, D.; Moritz, R.F.A.; Niemelä, J.; Rebane, M.; et al. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe—A review. *Agric. Ecosyst. Environ.* **2008**, *124*, 60–71. [[CrossRef](#)]
4. MacDonald, D.; Crabtree, J.R.; Wiesinger, G.; Dax, T.; Stamou, N.; Fleury, P.; Gutierrez Lazpita, J.; Gibon, A. Agricultural abandonment in mountain areas of Europe: Environmental consequences and policy response. *J. Environ. Manag.* **2000**, *59*, 47–69. [[CrossRef](#)]
5. Strijker, D. Marginal lands in Europe—Causes of decline. *Basic Appl. Ecol.* **2005**, *6*, 99–106. [[CrossRef](#)]
6. Bernués, A.; Ruiz, R.; Olaizola, A.; Villalba, D.; Casasús, I. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. *Livest. Sci.* **2011**, *139*, 44–57. [[CrossRef](#)]
7. Gerber, P.J.; Steinfeld, H.; Henderson, B.; Mottet, A.; Opio, C.; Dijkman, J.; Falcucci, A.; Tempio, G. *Tackling Climate Change through Livestock—A Global Assessment of Emissions and Mitigation Opportunities*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2013.
8. Cederberg, C.; Persson, U.M.; Neovius, K.; Molander, S.; Clift, R. Including Carbon Emissions from Deforestation in the Carbon Footprint of Brazilian Beef. *Environ. Sci. Technol.* **2011**, *45*, 1773–1779. [[CrossRef](#)] [[PubMed](#)]
9. Ogino, A.; Sommart, K.; Subepang, S.; Mitsumori, M.; Hayashi, K.; Yamashita, T.; Tanaka, Y. Environmental impacts of extensive and intensive beef production systems in Thailand evaluated by life cycle assessment. *J. Clean. Prod.* **2016**, *112*, 22–31. [[CrossRef](#)]
10. De Vries, M.; de Boer, I.J.M. Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livest. Sci.* **2010**, *128*, 1–11. [[CrossRef](#)]
11. Galka, A. Using a cleaner production preventive strategy for the reduction of the negative environmental impacts of agricultural production—Using cattle husbandry as a case study. *J. Clean. Prod.* **2004**, *12*, 513–516. [[CrossRef](#)]
12. Pelletier, N.; Pirog, R.; Rasmussen, R. Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. *Agric. Syst.* **2010**, *103*, 380–389. [[CrossRef](#)]
13. De Vries, M.; van Middelaar, C.E.; de Boer, I.J.M. Comparing environmental impacts of beef production systems: A review of life cycle assessments. *Livest. Sci.* **2015**, *178*, 279–288. [[CrossRef](#)]

14. Bragaglio, A.; Napolitano, F.; Pacelli, C.; Pirlo, G.; Sabia, E.; Serrapica, F.; Serrapica, M.; Braghieri, A. Environmental impacts of Italian beef production: A comparison between different systems. *J. Clean. Prod.* **2018**, *172*, 4033–4043. [[CrossRef](#)]
15. Plieninger, T.; Höchtl, F.; Spek, T. Traditional land-use and nature conservation in European rural landscapes. *Environ. Sci. Policy* **2006**, *9*, 317–321. [[CrossRef](#)]
16. De Rancourt, M.; Fois, N.; Lavín, M.P.; Tchakérian, E.; Vallerand, F. Mediterranean sheep and goats production: An uncertain future. *Small Rumin. Res.* **2006**, *62*, 167–179. [[CrossRef](#)]
17. Sitz, B.M.; Calkins, C.R.; Feuz, D.M.; Umberger, W.J.; Eskridge, K.M. Consumer sensory acceptance and value of domestic, Canadian, and Australian grass-fed beef steaks¹. *J. Anim. Sci.* **2005**, *83*, 2863–2868. [[CrossRef](#)] [[PubMed](#)]
18. De Groot, R.S.; Wilson, M.A.; Boumans, R.M.J. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecol. Econ.* **2002**, *41*, 393–408. [[CrossRef](#)]
19. Braghieri, A.; Pacelli, C.; Bragaglio, A.; Sabia, E.; Napolitano, F. The hidden costs of livestock environmental sustainability: The case of Podolian cattle. In *The Sustainability of Agro-Food and Natural Resource Systems in the Mediterranean Basin*; Vastola, A., Ed.; Springer: Cham, Switzerland, 2015.
20. De Groot, R.S. *Functions of Nature: Evaluation of Nature in Environmental Planning, Management and Decision Making*; Wolters-Noordhoff BV: Groningen, The Netherlands, 1992; ISBN 90-01-35594-3.
21. Ripoll-Bosch, R.; de Boer, I.J.M.; Bernués, A.; Vellinga, T.V. Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: A comparison of three contrasting Mediterranean systems. *Agric. Syst.* **2013**, *116*, 60–68. [[CrossRef](#)]
22. Kiefer, L.R.; Menzel, F.; Bahrs, E. Integration of ecosystem services into the carbon footprint of milk of South German dairy farms. *J. Environ. Manag.* **2015**, *152*, 11–18. [[CrossRef](#)]
23. Pirlo, G. *Cradle-to-farm* gate analysis of milk carbon footprint: A descriptive review. *Ital. J. Anim. Sci.* **2012**, *11*, e20. [[CrossRef](#)]
24. Pirlo, G.; Carè, S.; Fantin, V.; Falconi, F.; Buttol, P.; Terzano, G.M.; Masoni, P.; Pacelli, C. Factors affecting life cycle assessment of milk produced on 6 Mediterranean buffalo farms. *J. Dairy Sci.* **2014**, *97*, 6583–6593. [[CrossRef](#)]
25. Florindo, T.J.; de Medeiros Florindo, G.I.B.; Talamini, E.; da Costa, J.S.; Ruviaro, C.F. Carbon footprint and Life Cycle Costing of beef cattle in the Brazilian midwest. *J. Clean. Prod.* **2017**, *147*, 119–129. [[CrossRef](#)]
26. Thrane, M. LCA of Danish Fish Products. New methods and insights (9 pp). *Int. J. Life Cycle Assess.* **2006**, *11*, 66–74. [[CrossRef](#)]
27. Casasús, I.; Bernués, A.; Sanz, A.; Villalba, D.; Riedel, J.L.; Revilla, R. Vegetation dynamics in Mediterranean forest pastures as affected by beef cattle grazing. *Agric. Ecosyst. Environ.* **2007**, *121*, 365–370. [[CrossRef](#)]
28. Benton, T.G.; Vickery, J.A.; Wilson, J.D. Farmland biodiversity: Is habitat heterogeneity the key? *Trends Ecol. Evol.* **2003**, *18*, 182–188. [[CrossRef](#)]
29. Kramer, K.; Groen, T.A.; van Wieren, S.E. The interacting effects of ungulates and fire on forest dynamics: An analysis using the model FORSPACE. *For. Ecol. Manag.* **2003**, *181*, 205–222. [[CrossRef](#)]
30. Throsby, C.D. *Economics and Culture*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2001; ISBN 978-0-521-58406-7.
31. Benhamou, F. Heritage. In *A Handbook of Cultural Economics, Cheltenham: Edward Elgar*; Towse, R., Ed.; Edward Elgar Cheltenham: Cheltenham, UK, 2003; pp. 255–262.
32. Guinée Jeroen, B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; de Koning, A.; van Oers, L.; Wegener Sleswijk, A.; Suh, S. Life Cycle Assessment—An Operational Guide to the ISO Standards; 2001. Available online: https://pdfs.semanticscholar.org/8465/dac2aa2ee701363a1e6587f71e2d75178db6.pdf?_ga=2.65134507.423360027.1588788501-287539041.1517164762. (accessed on 17 April 2020).
33. ISO 14040 Environmental management. Life cycle assessment. In *Principles and Framework*; Switzerland 2006. Available online: <https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:en> (accessed on 17 April 2020).
34. ISO 14040 Environmental management. Life cycle assessment. In *Requirements and Guidelines*; Switzerland 2006. Available online: <https://www.iso.org/standard/37456.html> (accessed on 17 April 2020).
35. IPCC. Chapter 10—Emissions from Livestock and manure management. In *Agriculture, Forestry and Other Land Use*; 2006; Volume 4, p. 10. Available online: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf (accessed on 6 June 2016).

36. IPCC. Chapter 11—N₂O Emission from Management Soil, and CO₂ Emission from Lime and Urea Application. In *Agriculture, Forestry and Other Land Use*; 2006; Volume 4, pp. 11.5–11.53. Available online: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf (accessed on 6 June 2016).
37. Napolitano, F.; Caporale, G.; Carlucci, A.; Monteleone, E. Effect of information about animal welfare and product nutritional properties on acceptability of meat from Podolian cattle. *Food Qual. Prefer.* **2007**, *18*, 305–312. [[CrossRef](#)]
38. Heijungs, R.; Guinée, J.B. *Environmental Life Cycle Assessment of Products*; Centre of Environmental Science: Leiden, The Netherlands, 1992; ISBN 978-90-5191-064-3.
39. Dumont, B.; Ryschawy, J.; Duru, M.; Benoit, M.; Chatellier, V.; Delaby, L.; Donnars, C.; Dupraz, P.; Lemauviel-Lavenant, S.; Méda, B.; et al. Review: Associations among goods, impacts and ecosystem services provided by livestock farming. *Animal* **2019**, *13*, 1773–1784. [[CrossRef](#)]
40. Esposito, G.; Masucci, F.; Napolitano, F.; Braghieri, A.; Romano, R.; Manzo, N.; Di Francia, A. Fatty acid and sensory profiles of Caciocavallo cheese as affected by management system. *J. Dairy Sci.* **2014**, *97*, 1918–1928. [[CrossRef](#)]
41. Napolitano, F.; Pacelli, C.; De Rosa, G.; Braghieri, A.; Girolami, A. Sustainability and welfare of Podolian cattle. *Livest. Prod. Sci.* **2005**, *92*, 323–331. [[CrossRef](#)]
42. ISMEA, Istituto di Servizi per il Mercato Agricolo e Alimentare 2017. Available online: <http://www.ismeamercati.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/3713#d32ff4> (accessed on 23 November 2017).
43. Ezebilo, E.E. Economic value of a non-market ecosystem service: An application of the travel cost method to nature recreation in Sweden. *Int. J. Biodivers. Sci. Ecosyst. Serv. Manag.* **2016**, 1–14. [[CrossRef](#)]
44. Via Michelin Percorsi. 2016. Available online: <https://www.viamichelin.it/web/itinerari> (accessed on 5 September 2016).
45. Sabia, E.; Napolitano, F.; Claps, S.; De Rosa, G.; Barile, V.L.; Braghieri, A.; Pacelli, C. Environmental impact of dairy buffalo heifers kept on pasture or in confinement. *Agric. Syst.* **2018**, *159*, 42–49. [[CrossRef](#)]
46. Castanheira, É.G.; Dias, A.C.; Arroja, L.; Amaro, R. The environmental performance of milk production on a typical Portuguese dairy farm. *Agric. Syst.* **2010**, *103*, 498–507. [[CrossRef](#)]
47. Nguyen, T.L.T.; Hermansen, J.E.; Mogensen, L. Environmental consequences of different beef production systems in the EU. *J. Clean. Prod.* **2010**, *18*, 756–766. [[CrossRef](#)]
48. Dick, M.; Abreu da Silva, M.; Dewes, H. Life cycle assessment of beef cattle production in two typical grassland systems of southern Brazil. *J. Clean. Prod.* **2015**, *96*, 426–434. [[CrossRef](#)]
49. Greenwood, P.L.; Paull, D.R.; McNally, J.; Kalinowski, T.; Ebert, D.; Little, B.; Smith, D.V.; Rahman, A.; Valencia, P.; Ingham, A.B.; et al. Use of sensor-determined behaviours to develop algorithms for pasture intake by individual grazing cattle. *Crop Pasture Sci.* **2017**, *68*, 1091. [[CrossRef](#)]
50. Tedeschi, L.O.; Molle, G.; Menendez, H.M.; Cannas, A.; Fonseca, M.A. The assessment of supplementation requirements of grazing ruminants using nutrition models. *Transl. Anim. Sci.* **2019**, *3*, 811–828. [[CrossRef](#)]
51. IPCC. Chapter 2—Generic Methodologies applicable to multiple land-use categories. In *Agriculture, Forestry and Other Land Use*; 2006; Volume 4, pp. 2.6–2.54. Available online: https://www.ipccnggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf (accessed on 17 April 2020).
52. Hocquette, J.-F.; Ellies-Oury, M.-P.; Lherm, M.; Pineau, C.; Deblitz, C.; Farmer, L. Current situation and future prospects for beef production in Europe—A review. *Asian-Australas. J. Anim. Sci.* **2018**, *31*, 1017. [[CrossRef](#)]
53. Gerber, P.J.; Mottet, A.; Opio, C.I.; Falcucci, A.; Teillard, F. Environmental impacts of beef production: Review of challenges and perspectives for durability. *Meat Sci.* **2015**, *109*, 2–12. [[CrossRef](#)]

