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Carbon footprint in different beef production systems on a southern Brazilian farm: a case study

Clandio F. Ruviaro [a,d,*], Cristiane Maria de Léis [b,1], Vinícius do N. Lampert [c,1], Júlio Otávio Jardim Barcellos [d], Homero Dewes [d,e]

[a] *Agribusiness Postgraduate Program, FACE, UFGD, Dourados, Brazil*
[b] *Environmental Engineering Postgraduate Program, PPGEA, UFSC, Florianópolis, Brazil*
[c] *Brazilian Agricultural Research Corporation, EMBRAPA-CPPSUL, Bagé, Brazil*
[d] *Center for Research in Agribusiness, CEPAN, UFRGS, Porto Alegre, Brazil*
[e] *Biophysics Department, Biosciences Institute, UFRGS, Brazil*

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A B S T R A C T

The carbon footprint (CF) of beef production is one of the most widely discussed environmental issues within the current agricultural community due to its association with climate change. Because of these relevant and serious concerns, the beef cattle industry is under increasing pressure to reduce production or implement technological changes with significant consequences in terms of beef marketing. The goals of this study were to evaluate the CF per 1 kg of live weight gain (LWG) at the farm gate for different beef production systems in the southern part of Brazil. Aberdeen Angus beef-bred cattle were assigned to one of seven categories: natural grass; improved natural grass; natural grass plus ryegrass; improved natural grass plus sorghum; cultivated ryegrass and sorghum; natural grass supplemented with protein mineralised salt; and natural grass supplemented with protein-energetic mineralised salt. Monte Carlo analysis was employed to analyse the effect of variations of dry matter intake digestibility (DMID), total digestible nutrients (TDN) and crude protein (CP) parameters in methane (CH_4) enteric, CH_4 manure, nitrous oxide (N_2O) manure and N_2O N-fertiliser. The method used was a comparative life cycle assessment (LCA) centred on the CF. The CF varied from 18.3 kg CO_2 equivalent/kg LWG for the ryegrass and sorghum pasture system to 42.6 kg CO_2 equivalent/kg LWG for the natural grass system, including the contributions of cows, calves and steers. Among all grassland-based cattle farms, production systems with DMID from 52 to 59% achieved the lowest CO_2 emissions and the highest feed conversion rate, thereby generating lower CH_4 and N_2O emissions per production system. Because the feed intake and feed conversion rate are one of the most important production parameters in beef cattle production with an obvious risk of data uncertainty, accurate feed data, which include quantity and quality, are important in estimates of CF for LWG. The choice of adequate feeding strategies to mitigate greenhouse gas (GHG) emissions may result in better environmental advantages.

1. Introduction

Beef cattle production is one of the most important agricultural activities in Brazil and is characterised by a large number of animals and extensive pasture. The Brazilian beef industry is under considerable pressure from national and international communities concerned with global warming based upon the notion that cattle production is responsible for over 50% of national greenhouse gas (GHG) emissions, which are directly related to the agricultural sector. From these emissions, 45% are caused by cattle enteric fermentation (methane, CH_4), as well as urine and faeces decomposition, which releases nitrous oxide (N_2O), and other less relevant gases (Bungenstab, 2012). The Brazilian herd has approximately 205 million heads occupying 170 million hectares of pasture according to a census of the Brazilian Institute of Geography and Statistics (IBGE, 2008).

In the southern Brazilian state of Rio Grande do Sul, there are approximately 13.2 million heads of cattle in 11.7 million hectares,

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* Corresponding author. Universidade Federal da Grande Dourados, Programa de Pós-Graduação em Agronegócios (FACE) Rodovia Dourados-Itahum, Km 12, Dourados, MS CEP: 79800-000, Brazil. Tel./fax: +55 67 3410 2063.

E-mail addresses: 00184298@ufrgs.br, clandioruviaro@ufgd.edu.br, clandioruviaro@hotmail.com (C.F. Ruviaro).

[1] Universidade Federal da Grande Dourados, Programa de Pós-Graduação em Agronegócios (FACE) Rodovia Dourados-Itahum, Km 12, Dourados, MS CEP: 79800-000, Brazil. Tel./fax: +55 67 3410 2063.

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which is approximately 53.7% of the total area of this state (IBGE, 2008). In this region, beef production relies on the management of natural pasture as the main source of animal feed. These grasslands exhibit high biodiversity and are characterised by high production and high nutritional quality during spring and summer but low production and low nutritional quality during autumn and winter when it is necessary to use cultivated pastures or supplementation as feed support. The regional pastures show more than 450 species of native grasses and approximately 150 species of legumes. Local biodiversity losses could affect the potential for sustainable animal and plant production in this region due to the loss of valuable species of natural forages, feed, food, ornamental and medicinal species and the reduction of environmental services provided by grassland vegetation, such as erosion control and soil carbon sequestration, which can mitigate climate change (Pillar et al., 2009). Thus, the local cattle industry is under scrutiny from both producers and the public.

In Brazil, approximately 70% of CH_4 emissions are derived from cattle production (MCT, 2010). Most of the CH_4 has its origin in enteric fermentation and is a physiological result of digestion in ruminant animals. These emissions represent, in part, the natural inefficient capture of energy contained in animal feed. The use of such techniques as the intensification of activity via the appropriate management of pastures and improved quality of food supplied to animals mitigates the production of GHG (Bungenstab, 2012; Harper et al., 1999; McAllister et al., 2011; O'Hara et al., 2003).

Thus, better pasture management, supplementary feeding practices, substitution of forage for food containing less fibre, adequate sanitary control, integrated management of animal wastes and the genetic improvement of animals are techniques that may improve livestock productivity and reduce emissions linked to beef cattle production (Barioni et al., 2007; Boadi et al., 2004; Iqbal et al., 2008; Oliveira et al., 2007; Pedreira et al., 2004; Segnini et al., 2007; Wilkins and Hump, 2003).

Emissions from cattle have been attributed to production processes that involve inputs (e.g., fertilisers and forage cultivation) and production itself (CO_2, CH_4 and N_2O). Regarding the latter, CH_4 emissions are produced by enteric fermentation and manure, and N_2O emissions are emitted mostly by manure. There is also the potential use of nitrogen fertilisers in pastures emitting N_2O (Luo et al., 2010). Among these GHG, the most important is CH_4, due to the relatively large amount emitted (Beauchemin et al., 2008; Biswas et al., 2010; Steinfeld et al., 2006).

Seasonal changes in cattle production efficiency combined with the constant attention given by the media in highlighting beef cattle as a major source of GHG, has pushed for limitations of the cattle herds in an attempt to minimise their putative, negative and environmental effects. Analysis of the carbon footprint (CF) of cattle production identifies the production procedures or techniques in which emissions may be reduced using improved efficiencies, estimates the amount and breakdown of GHG emissions and provides a mechanism to track efforts in improving efficiencies and reducing emissions (Wiedmann and Minx, 2008).

The aim of this study was to quantify and analyse the variability of emissions, as CF per functional unit (FU), for typical southern Brazilian beef production systems with different options for animal feed intake data obtained from a beef cattle farm, and from Brazilian governmental reports and databases. For this purpose, we required definitions for (a) the typical beef production systems operating in southern Brazil; (b) the system boundary and functional unit to be applied; and (c) the dietary and scenario options to be considered in southern Brazilian beef production that may lead to reduced GHG emissions.

2. Methods

The contribution to climate change associated with seven different production systems was evaluated using a Life Cycle Assessment (LCA) approach (Finnveden et al., 2009; Guinée et al., 2001). This study uses LCA methodology to relate default data provided by Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2007) for CO_2, CH_4, and N_2O emissions related to feed and animal manure with data now available from the Brazilian Agricultural Research Corporation (EMBRAPA) (Lima et al., 2012; MCT, 2010).

In the inventory analysis phase, inputs from the environment (resources used) and outputs to the environment (emissions) associated with the product were considered. In the impact assessment phase, inputs and outputs were interpreted in terms of Global Warming Potential (GWP).

2.1. Definition of the production system

This study was performed at a farm in the Western Frontier region of the state of Rio Grande do Sul (Fig. 1), in the Southern part of Brazil (28°56′11.78″S; 55°47′01.68″O).

This Western Frontier region has a large beef cattle herd (ca. 3,300,000 heads), which is approximately 22% of the total cattle herd in this state (IBGE, 2008). The climatic classification of the region is wet subtropic Cfa in Koeppen classification (Koeppen, 1948), and the average precipitation is 1598 mm/year, without periodical dry seasons. The average annual temperature is 19.8 °C. Cattle are bred extensively; the herds forage on natural and cultivated pasture with variable stocking rates, and they are the source for most of the meat production in this region.

In addition to natural grass, other pastures for beef cattle feed include improved natural grass (a mixture of natural grass, ryegrass and clover), and ryegrass and sorghum. In the farm analysed, all farmed animals are of the *Bos taurus* breed (Aberdeen angus). It was assumed that calves are weaned at approximately 180 days and that from this period onwards, the animals graze on grass. From 180 days to when the fattening weight is attained, the animals are allowed to graze on grass according to the scenarios described in Section 2.2. The animal fattening weight was 430 kg live weight for all the scenarios.

The data used in this paper are the average of data collected during six years of observation of 420 animals in different cattle

Fig. 1. Geographical position of Rio Grande do Sul. Source: GoogleMaps (2013).

production systems that are commonly used in the region. Analysed data in this case study were related to São Lucas Farm (São Borja city) that has a pastoral surface of 2,370 ha (ha), an occupancy of 1,800 animal units (A.U.) and it has a productivity of 139 kg live weight/ha. Besides, it has marketed 306,000 kg live weight/year resulting in an annual income circa US$ 400,000. Moreover, the farm continuously has been specializing in intensive livestock system.

2.2. *Description of scenarios*

In this study, the scenarios used were developed using Angus beef-bred animals utilised in typical Southern Brazilian beef production systems as castrated males. The scenarios were designed according to the different feeding regimens that the animals were raised upon (Table 1).

These scenarios were chosen because they represent the most frequently used beef cattle production systems in the region. The system was modified to consider the life cycle from pregnant cows (281 days) to fattened steers with a 430 kg final live weight in all scenarios. Changes in the number of days required for each animal to reach the final live weight, under the different scenarios were due to the differences in the nutritional quality of the animals' respective diets.

The amount of synthetic N-fertiliser applied in scenario II, III, IV and V was 12.5, 105, 85 and 165 kg of N/hectare, respectively.

Differences in the nutritional quality of the diets occurred in the same and in different scenarios. The effects of the variability in the quality of the same ingredient in the emission of GHG were obtained by examining the interval of typical values for each ingredient within each scenario (Table 2).

Within each scenario, in the different scenarios, and in every age-related animal category, the values changed for live weight, live weight gain, interval from calving to fattening, and stock rate (Table 2).

Several nutritional factors have been identified in the literature, which affect the rate of enteric CH_4 production in beef cattle; the key factors are related to DM intake, DM digestibility, and animal productivity (Merino et al., 2011).

2.3. *Data source*

The data considered in this work were gathered during a period of six consecutive years (from 2005 to 2011). A model based on the nutrient requirements and metabolism of animals of different beef production systems was used to quantify the CF. The method used a cradle to farm-gate approach substantiated on life cycle assessment principles whereby all relevant inputs and outputs from the beef production system were included, with the system boundaries set as shown in Fig. 2.

Primary inputs included animal feed (mineralised salt, energetic salt and protein-energetic salt), and electricity and fuel for forage soil preparation and transportation of mineralised salt to farm. Secondary inputs included chemicals (fertilisers and pesticides) applied to forage, and fuel for forage practices and agrochemical manufacture. The nutrient requirements of individual animals were calculated using the Nutrient Requirements of Beef Cattle (NRC, 2000). Animal diets were formulated to provide the feed requirements of the animals within each subsystem according to body weight, sex and live weight gain. The CF was assessed by comparing the annual inputs and outputs under each scenario in the same period (days) and was expressed per live weight gain (LWG). Land use change was not taken into account in any of the scenarios and potential changes in soil carbon were ignored due to the current lack of relevant Southern Brazilian data.

Table 1
Description of scenarios, productions systems and period of grazing.

Scenarios	Production systems	Period (days)
I	Natural grass	840
II	Improved natural grass	510
III	Natural grass/ryegrass	510/159
IV	Improved natural grass/sorghum	360/125
V	Cultivated ryegrass and sorghum	502
VI	Natural grass supplemented with protein mineralised salt	660
VII	Natural grass supplemented with protein-energetic mineralised salt	510

Table 2
Values for live weight, live weight gain, interval from calving to fattening, and stock rate used to estimate the GHG emissions of cattle production in different nutritional scenarios.

Scenarios		Age, mo					
		6	12	18	24	30	
	Live weight, kg						
I		165	195	280	325	430	
II		190	330	430	–	–	
III		165	195	280	430	–	
IV		190	330	430	–	–	
V		190	330	430	–	–	
VI		220	260	360	430	–	
VII		220	260	430	–	–	
	Live weight gain, kg						Total
I		133	30	85	45	105	398
II		158	140	100	–	–	398
III		133	30	85	150	–	398
IV		158	140	100	–	–	398
V		158	140	100	–	–	398
VI		188	40	100	70	–	398
VII		188	40	170	–	–	398
	Interval from calving to fattening, *d*						
I		180	150	180	150	180	840
II		180	180	150	–	–	510
III		180	150	180	159	–	669
IV		180	180	125	–	–	485
V		180	180	142	–	–	502
VI		180	150	180	150	–	660
VII		180	150	180	–	–	510
	Live weight supported, kg/ha						Means
I		397	397	397	397	397	397
II		716	716	716	–	–	716
III		397	397	397	930	–	530
IV		716	716	1150	–	–	861
V		930	930	930	–	–	930
VI		380	380	388	380		382
VII		380	380	380	–	–	380

2.4. *The system boundary*

The system boundary was defined by the GHG emissions associated with Southern Brazilian beef production from "cradle to farm-gate" (Fig. 2).

The LCA of the production systems included natural grass, cultivated forages (natural grass plus ryegrass and clover, ryegrass, or sorghum), natural grass supplemented with protein-energetic mineralised salt and the resources used to produce these components (e.g., diesel and fertilisers), and all transportation effects, including the transport of components to the farm where they were consumed by the herd. Data concerning resource use and emissions associated with the production and delivery of the inputs for forage cultivation (fertilisers, diesel, and agricultural machinery) were

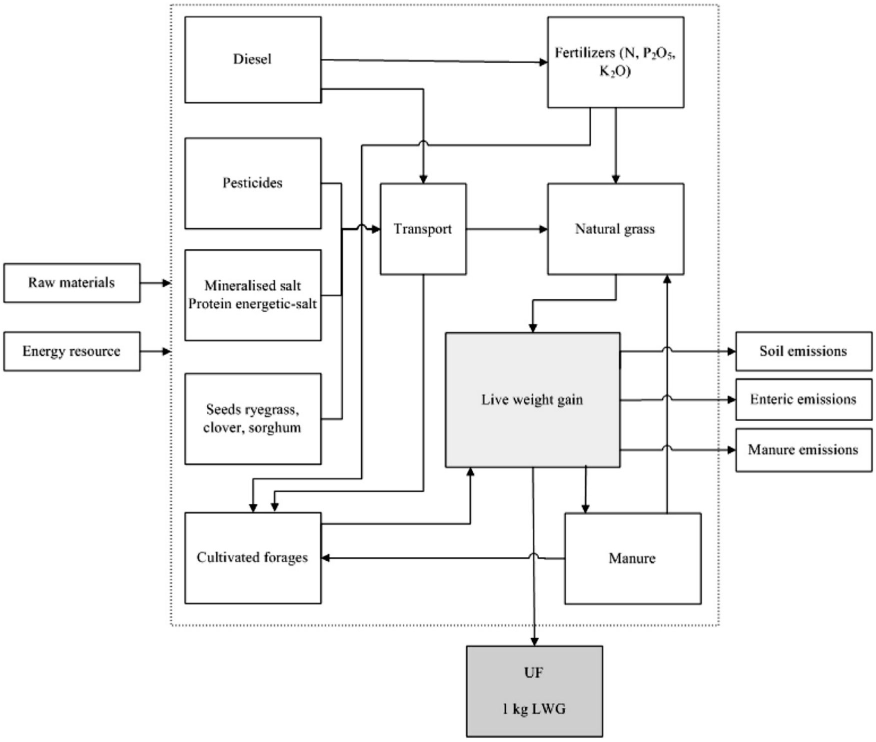

Fig. 2. System Boundaries of Southern Brazilian beef production from “cradle to farm-gate”.

obtained from the Ecoinvent database, version 3.0 (Nemecek et al., 2007).

The model included the physical limits of beef unit and associated activity: emissions associated with nitrogen fertiliser production, transportation and delivery into the soil; emissions associated with animals; and emissions associated with the diesel used for agricultural work on the farm. The following GHG sources were considered: on-farm CH_4 emissions from cattle and manure; on-farm N_2O emissions from manure and soils; and run-off and volatilisation of indirect N_2O emissions. The emissions associated with the production of medicines and pesticides were excluded due to the lack of available data (Cederberg and Mattsson, 2000). CO_2 from enteric fermentation was excluded from the study because this gas was considered neutral with respect to GHG emissions (IPCC, 2007).

2.5. Functional unit and allocation

Comparisons of beef production systems demands consistent FU. In this study, the FU used for all flows within each system studied was “1 kg live weight gain at the farm gate”. This FU was a measure of the performance of a production system in which all inputs and outputs were related (ISO, 2006b). This FU became one of the most used environmental protection indicators of animal production (Galli et al., 2012; Lam et al., 2010).

2.6. Impact category

In this study, we analyse the CF related to global warming. The GWP over a 100 years-time horizon was used to determine the contribution of CO_2, CH_4 and N_2O to the greenhouse effect (IPCC, 2007). Among different categories of environmental impacts, the CF has received the most current attention (Wiedmann and Minx, 2008). The CF was estimated for the average regional beef production using a standardised method of LCA (ISO, 2006a, 2006b) to calculate the environmental impact of a product from a life cycle perspective. The CF estimation using LCA (Crosson et al., 2011; Čuček et al., 2012) considers the resources used in production, as well as the production of gases during the production process (Peters et al., 2010). Calculations were performed using the LCA software tool SimaPro 7.3.2 (PRéConsultants, 2010). These gases have different GWP when converted to carbon dioxide equivalents (CO_2), which is a metric measure used to compare emissions from various GHG in which the GWP is based. Each kg of CO_2, CH_4 and N_2O released into the atmosphere is equivalent to 1 kg, 25 kg and 298 kg of carbon dioxide, respectively (IPCC, 2007). The analyses of other impact categories in the beef cattle industry in Brazil are currently hindered by the lack of reliable sources of data.

2.7. Emission factors

Enteric CH_4 emissions were calculated using the equations obtained from IPCC (Dong et al., 2006). The input data in this model were the animal live weights, which were used to estimate the energy required for maintenance, and the beef yield to estimate the energy required for meat production. In addition, the energy content in feed intake, and the proportions of roughage feed and crude protein in the total dry matter intake (DMI) were used to estimate the CH_4 and N_20 emissions (Dong et al., 2006; NRC, 2000).

Emission factors (EFs) for N_2O from manure were based on data obtained from Primavesi et al. (2012). Over the duration of each life cycle stage in all production systems, the environmental inventory was limited to emissions of enteric CH_4 and soil manure, CH_4, N_2O emissions from urea, and N_2O emissions from manure. The emissions from animals were calculated according to the data obtained from chapter 10 of the IPCC (Dong et al., 2006) using equations 10.21, 10.23, 10.24, 10.25 (Table 3) and Table 10.17.

Methane emissions from manure and excreta deposited on the field during grazing were calculated according to Tier 2 protocols from the IPCC guidelines (IPCC, 2007). The emission factors and

Table 3
Equation used and reference source to animal emissions.

Source	Equation	References
Equation 10.21/CH_4 emission factors for enteric fermentation	$EF = [GE \times (Ym/100) \times 365/55.65]$	Dong et al. (2006)
Equation 10.23/CH4 emission factor from manure management	$EF_{(T)} = (VS_{(T)} \times 365) \times [\ B_{o(T)} \times 0.67\ kg/m^3 \times \sum_{S,k} MCF_{S,k}/100 \times MS_{(T,S,k)}]$	Dong et al. (2006)
Equation 10.24/Volatile solid excretion rates	$VS = [GE \times (1 - DE\%/100) + (UE\ GE)] \times [(1 - ASH/18.45)]$	Dong et al. (2006)
Equation 10.25/Direct N_2O emissions from manure management	$N_2O_{D\ (mm)} = [\sum_S [\sum_T (N_{(T)} \times Nex_{(T)} \times MS_{(T,S)})] \times EF_{3(S)}\ ] \times 44/28$	Dong et al. (2006)

EF = emission factor; GE = gross energy intake; Ym = methane conversion factor; Factor 55.65 energy content methane; $EF_{(T)}$ = annual CH_4 emission factor; $VS_{(T)}$ = daily volatile solid excreted; 365 = basis for calculating annual VS production; $Bo_{(T)}$ = maximum methane producing capacity for manure; 0.67 = conversion factor; $MCF_{(S,k)}$ = methane conversion factors; $MS_{(T,S,k)}$ = fraction of livestock category; VS = volatile solid excretion; DE% = digestibility of the feed; (UE·GE) = urinary energy; ASH = the ash content of manure; 18.45 = conversion factor for dietary GE; $N_2OD(mm)$ = direct N_2O emissions from manure management; $N_{(T)}$ = number of head of livestock; $Nex_{(T)}$ = annual average N excretion; $MS_{(T,S)}$ = fraction of total annual nitrogen excretion; $EF3_{(S)}$ = emission factor for direct N_2O emissions; S = manure management system; T = species/category of livestock; 44/28 = conversion of (N_2O–N)(mm) emissions to N_2O(mm) emissions.

methane conversion factors (MCFs) were calculated following Tier 2 protocols and adjusted following the analysis protocols in Lima et al. (2006) and MCT (2010). Tier 2 protocols were employed to calculate the enteric methane emissions due to the sensitivity of the emissions to the production system and the importance of methane emissions to the overall GHG emissions in beef cattle production. In this study, a 6% conversion factor (Ym) was applied to the pasture data (Dong et al., 2006; Johnson and Johnson, 1995; Primavesi et al., 2012). The production of manure was calculated based on the DMI with digestibility varying according to the forage type in each production system (Peripolli et al., 2011; Valadares Filho et al., 2010).

Direct emissions of N_2O from soil and EF values were calculated as recommended by the IPCC (2007) with adjustments as previously described in Alves et al. (2012) using equations 11.2 and 11.5 from chapter 11 with the measured nitrogen intake and nitrogen retained (Table 4).

The nitrogen applied to the soil as fertiliser was calculated as nitrogen in urea, as recommended by SBCS (2004). The nitrogen in excreta was calculated as the total amount of N in feed DMI subtracted from the amount of N in beef (calves and growth). The indirect emissions of N_2O caused by the volatilisation of ammonia (NH_3) and leaching of nitrate (NO_3) were estimated using EF values according to the IPCC (2007).

2.8. Monte Carlo analysis

To capture the inherent variability of ingredients in beef cattle production systems in this study, we used Monte Carlo analysis (MC). This tool simulates a probable range of outcomes given a set of variable conditions and can be applied within a risk assessment or Life Cycle Inventory framework to capture parameter variability (Huijbregts et al., 2001; Miller et al., 2006; Henriksson et al., 2011). Thus, MC is a technique employed to quantify variability and uncertainty using probability distributions. The effect of variations in the production data on the CF was analysed using MC analysis based on 5000 iterations, in which the probability distribution of CF was estimated for Brazilian beef cattle. The MC analysis was performed using @Risk of Palisade Corporation and SimaPro 7.3. Because no data bank on the nutritional data of the diet used was currently available, to the best of our knowledge, a triangular distribution was assumed for all parameters in the analysis.

3. Results and discussion

The evaluation of strategies for mitigation and adaptation usually occurs at scales at which interventions can be performed (e.g., production system, region, country). Recent publications have reported the use of LCA to determine all or a portion of the GHG emissions from the measured inputs and outputs related to beef production systems (Avery and Avery, 2008; Beauchemin et al., 2011; Cederberg et al., 2011; Dollé et al., 2011; McAllister et al., 2011; Schils et al., 2007; Sejian et al., 2011; Place and Mitloehner, 2012; Veysset et al., 2010).

The application of and comparisons among existing LCA studies may be limited due to differences in goals, system boundaries or functional units. Creating LCA models that account for different management strategies and technologies is critical because there is increasing consumer interest in sustainable beef production, as well as a need for a complete analysis of these different systems.

The parameters used in the analysis were Dry Matter Intake Digestibility (DMID), Total Digestible Nutrients (TDN), and Crude Protein (CP) because they exhibit a close interrelation with CH_4 enteric, CH_4 manure, N_2O manure, and N_2O N-fertiliser emissions (Table 5). This information on DMID, TDN and CP was calculated for each diet in each scenario according to the NRC (2000), Peripolli et al. (2011), and Valadares Filho et al. (2010).

In the seven scenarios analysed (Table 1), the CF was predominantly affected by CH_4 emissions ranging from 86 to 98%, which were mostly related to the beef cattle themselves. MC analysis was used to analyse the effect of the variations of DMID, TDN and CP parameters in CH_4 enteric, CH_4 manure, N_2O manure and N_2O N-fertiliser. This was performed using the software @Risk. The mean and variability of the GHG was employed to calculate the CF using SimaPro 7.3 (Table 6).

Considering the data shown in Tables 2–4, the results obtained from the MC simulation may denote a low uncertainty using variations in DMID, TDN and CP for the scenarios examined.

The reason for the moderate differences in CH_4 enteric (Fig. 3) was due to the forage and grass quality variation for the DMID (Table 5), which was attributed to the specificity of the scenarios analysed. The N_2O N-fertiliser emissions oscillated from 57% to 82% of total N_2O emissions considering the amount of N synthetic fertiliser applied ranging from 85 to 165 kg/ha in scenarios III, IV and V.

Table 4
Equation used and reference source to manage soils and pasture.

Source	Equation	References
Equation 11.2/Direct N_2O emissions from managed soils	$N_2O_{Direct} - N = \sum i\ (F_{SN} + F_{ON})_i \times EF_{1i} + (F_{CR} + F_{SOM}) \times EF_1 + N_2O{-}N_{OS} + N_2O\text{-}N_{PRP}$	IPCC (2007)
Equation 11.5/N in urine and dung deposited by grazing animals on pasture	$F_{PRP} = \sum_T [(N_{(T)} \times Nex_{(T)}) \times MS_{(T.PRP)}]$	IPCC (2007)

EF_{1i} = emission factors; F_{PRP} = annual amount of urine and dung N deposited on pasture; $N_{(T)}$ = number of head of livestock; $Nex_{(T)}$ = annual average N excretion per head; $MS_{(T,PRP)}$ = fraction of total annual N excretion for each livestock species/category.

Table 5
Values for Dry Matter Intake Digestibility (DMID), Total Digestible Nutrients (TDN), and Crude Protein (CP) used as the main drivers of enteric CH4 emissions and energy utilisation efficiency of cattle production in different nutritional scenarios.

Scenarios	DMID (%)			TDN (%)			CP (%)		
	Min.	Mean	Max	Min.	Mean	Max	Min.	Mean	Max
I	34.31	45.33	53.81	50.28	58.23	62.91	6.73	8.30	10.89
II	54.57	63.74	73.98	56.21	63.33	68.80	9.71	15.50	20.82
III	39.55	50.50	58.99	50.80	59.67	65.13	8.07	10.41	12.98
IV	46.86	56.92	66.35	55.26	63.50	69.58	9.96	14.83	19.26
V	46.55	56.39	65.76	47.15	54.66	61.78	7.07	9.17	10.95
VI	34.43	45.33	53.74	50.20	58.23	62.90	6.73	8.30	10.89
VII	34.31	45.33	53.76	50.26	58.23	62.94	6.73	8.30	10.89

The feed intake from the pasture was likely the most uncertain parameter when considering beef production. This parameter was very significant for production systems with a high intake of forage or grass from animal grazing. If carbon sequestration in pastures was included in the CF estimates and if strategies used to reduce GHG emissions were discussed, then it is necessary to improve the knowledge concerning pasture feed intake.

The estimated CF ranged from 18.30 to 42.60 kg CO_2-e/kg LWG for a complete beef cattle system, including the contributions of cows, calves, and steers (Table 7).

The MC analysis provided data with 97.5% confidence interval for each scenario. Using the average, the ranking was scenario I, VI, III, VII, IV, II and V. However, the Monte Carlo analysis showed that there were situations in which the scenario II, IV, V and VII could change the position in this ranking (Table 7). Because feed intake and the feed conversion rate were one of the most important production parameters in beef cattle production with an obvious risk of data uncertainty, accurate feed data, including quantity and quality, were important in estimates of CF for the LWG.

The results indicated that when examined on an equal live-weight production basis, scenario I (natural grass), with 42.6 kg CO_2-e/kg LWG, was more greenhouse gas-intensive than scenario V (cultivated ryegrass and sorghum) with 20.0 kg CO_2-e/kg LWG. The least CO_2-e emitting production systems were scenario V and II, with 20.0 and 20.2 CO_2-e/kg of LWG, respectively, which produced fattened animals in 485 and 510 days, respectively. These results were close to those reported by Phetteplace et al. (2001), who estimated 15.5 kg CO_2-e/kg live weight for calf-to-beef systems. Our results were also similar to estimates obtained by Casey and Holden (2006) and Veysset et al. (2010) of 11 and 15 kg of CO_2-e/kg of live weight gain, respectively. Hacala and Le Gall (2006) estimated a CF between 11.33 and 14.69 kg CO_2-e/kg live weight in three suckler systems. Studies evaluating the CF of beef production in Japan (Ogino et al., 2004), Sweden (Koneswaran and Nierenberg, 2008) and Brazil (Cederberg et al., 2009), also reported similar values of total GHG emissions to our current study, ranging from 22,8 kg of CO_2-e/kg of beef to 32.3 kg of CO_2-e/kg of beef.

The highest CO_2-e emissions were from scenarios I and VI. These scenarios produced an average of 42.6 and 33.3 kg CO_2-e/kg LWG, respectively, with fattening periods of 840 and 660 days, respectively. These scenarios had the lowest DMID with an average value of 34.37%. Among all the grassland-based cattle farms, production systems with DMID from 52 to 59% achieved the lowest CO_2-e emissions and highest feed conversion rate. This indicated that they generated lower CH_4 and N_2O emissions per production system.

Importantly, it would be necessary to consider the relative intensity of the production system, stocking rate (number of animals raised and produced per hectare) and kilogramme of body weight gain obtained per hectare as the main drivers of the greenhouse gases emissions. The most intensive production systems, i.e., production systems with scenarios II, IV, V and VII with 510, 485, 485 and 510 days for producing fattened animals and a stocking rate of 716, 861, 930 and 380 kg/ha, respectively, had the lowest CO_2-e emitting scenarios (Table 1).

Scenario VII produced lower emissions (23.4 kg CO_2-e/kg LWG) despite the low DMID (45.33%). This was due to the protein-energetic mineralised salt used because it acts as an amender in the feed conversion rate and reduces the time to achieve the fattening weight (510 days). These results were consistent with those of other studies demonstrating that higher quality forage, the use of concentrated, essential oils or increased growth rates reduced methane and nitrous oxide emitted from manure, both of which are key emission gases (Benchaar and Greathead, 2011; Casey and Holden, 2006; Lovett et al., 2005).

Comparisons of these results with those obtained in previous studies revealed a number of difficulties. First, in Brazil, there are only a few studies on beef production using the Life Cycle Assessment methodology (Ruviaro et al., 2012). One very significant problem is the variation in choice of functional unit and time scale among studies (de Vries and de Boer, 2010). For example, a study of a Japanese beef fattening system (Ogino et al., 2004) estimated a 32.3 kg CO_2-e/kg of beef gain during the fattening of the animal, but this did not include cow emissions for the entire system. Furthermore, the production efficiency in the Japanese cattle system was very different from that observed in this study.

In another study of Brazilian beef cattle, Cederberg et al. (2011) estimated a CF from beef cattle production in the Legal Amazon Region. However, the estimates provided by Cederberg et al. were not sufficient for comparison because they assumed calving intervals of 20 months and 3–4 years to fattening. This is a production system that is used in a specific region and does not represent Brazilian norms. Thus, these issues make it difficult to compare the results of our study to those of Cederberg et al. (2011) due to differences in management practices and in the assumptions regarding the production systems. The corresponding regions of the studies were completely different in terms of soil, weather conditions, management, pasture, animal genetics, and other factors. Despite the large differences among studies, reflecting

Table 6
Values for CH_4 enteric, CH_4 manure, N_2O manure, and N_2O fertiliser emissions used in MC analysis to estimate the Carbon Footprint of cattle production in different nutritional scenarios.

Scenarios	CH_4, enteric			CH_4, manure			N_2O, manure			N_2O, fertiliser		
	Min.	Mean	Max	Min.	Mean	Max	Min.	Mean	Max	Min.	Mean	Max
I	0.28443	0.32705	0.43526	0.00272	0.00276	0.00278	0.00101	0.00131	0.00182	–	0.00000	–
II	0.18370	0.21336	0.26662	0.00184	0.00186	0.00188	0.00076	0.00120	0.00160	0.00017	0.00023	0.00031
III	0.22681	0.26287	0.35344	0.00258	0.00261	0.00263	0.00089	0.00126	0.00171	0.00124	0.00167	0.00237
IV	0.17482	0.20206	0.24859	0.00172	0.00174	0.00176	0.00070	0.00108	0.00144	0.00412	0.00498	0.00628
V	0.16889	0.20450	0.26413	0.00177	0.00179	0.00181	0.00061	0.00095	0.00123	0.00133	0.00173	0.00238
VI	0.26463	0.30570	0.41247	0.00254	0.00257	0.00260	0.00118	0.00149	0.00200	–	0.00000	–
VII	0.22618	0.26188	0.35578	0.00221	0.00223	0.00225	0.00093	0.00116	0.00153	–	0.00000	–

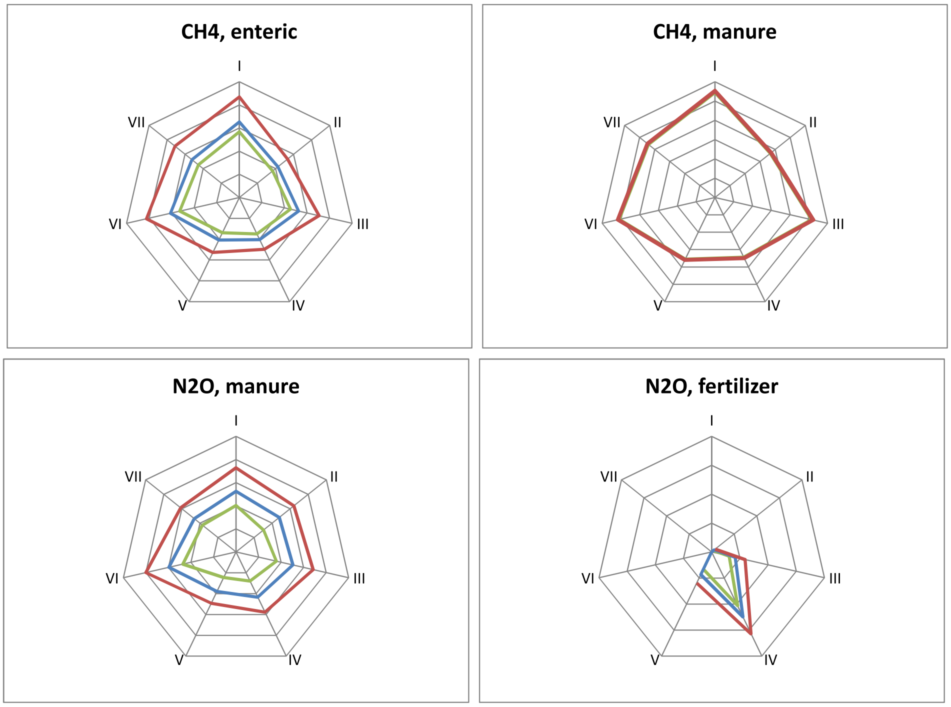

Fig. 3. Variability of estimated of greenhouse gas emissions (CH_4 enteric, CH_4 manure, N_2O manure and N_2O fertiliser) to the functional unit.

differences in the boundaries of the systems and assumed farming practices, our results were consistent with those of Pelletier et al. (2010). They considered a complete beef production system in which the fattening phase (more than 12 months) accounted for less than 36% of the total GHG emissions in the most efficient scenarios, similar to scenarios II, IV, V and VII of the current study and are the lowest CO_2-e emitting scenarios. The growth phase between calving and 6 months of age accounted for less than 19% of the total CO_2-e emissions in all these scenarios.

Considering the variation among published studies from the perspective and specific methodology of collection and analysis of data, we recognise that the results from specific regions cannot be used to compare beef production scenarios in different regions of the world. A comparison of various studies emphasises the effect of each production system and variation in efficiency on the estimated environmental impact.

4. Conclusions

The results show that improved natural grass (II) and cultivated ryegrass and sorghum (V) production systems have lower GHG emissions (20.2 and 20.0 kg CO_2-e/kg live weight gain) than other (e.g., natural grass with 42.6 CO_2-e/kg live weight gain) beef cattle production systems in the western frontier of the state of Rio Grande do Sul, Brazil. A modification in the quality of feed expressed in the variability of DMID, TDN and CP can alter the results and ranking positions of the scenarios concerning CF for live weight gain.

Furthermore, the generalisation of these conclusions to any other region of Brazil must consider the great heterogeneities in the country in terms of climate conditions, soil, natural grasses, cultivated forages, animal genetics, management, greenhouse gases emissions, biodiversity and many other aspects and differences in the local animal production systems.

Besides, the current trends in terms of the number of publications, channelling resources for research, governmental demands and generation of a growing volume of organised data on GHG flow suggest that the use of LCA to quantify the potential environmental impact of products from agricultural and livestock production and to support public policy will be an area of intense development in the near future.

Brazil continues to lack consolidated studies regarding the development of LCA and life cycle inventories of production processes and systems for the balancing of GHGs and other environmental impact categories. However, several groups from national institutions (e.g., the Federal University of Rio Grande do Sul, the University of São Paulo and EMBRAPA) have made consistent progress in the evaluation of emission factors based on national data as well as the evaluation and reparameterisation of process models developed abroad using national databases.

In addition, there has been recent progress towards the production of integrated models for scenario projection and assessment at a national level. Furthermore, the integration of dynamic mathematical models in methods of Life Cycle Assessment in Brazilian cattle production should soon be possible. However, a basic condition for this to occur is the construction of geographical databases of biophysical conditions, land use, prices and infrastructure.

Table 7
Summary of the calculated CO_2 equivalent inputs from each growth stage of each scenario.

Scenarios	CO_2 equivalent, kg CO_2-e/kg live weight gain				
	Min.	Mean	Max.	s.d[a]	CV %[b]
I	39.3	42.6	46.5	1.79	4.21
II	18.7	20.2	22.0	0.85	4.18
III	27.2	29.6	32.6	1.42	4.80
IV	21.1	23.4	25.4	1.04	4.44
V	18.3	20.0	21.8	0.91	4.52
VI	30.6	33.3	36.6	1.56	4.68
VII	21.1	23.4	26.1	1.26	5.40

[a] Standard deviation.
[b] Coefficient of variation is the average variance of the mean value.

Considering the lack of baseline data in Brazil as a whole, this study can support future LCA studies concerning livestock and agriculture issues in this country.

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Acronyms and Abbreviations

CF: Carbon Footprint
CP: Crude Protein
DMI: Dry Matter Intake
DMID: Dry Matter Intake Digestibility
EFs: Emission factors
FU: Functional Unit
GWP: Global Warming Potential
Ha: Hectare
LWG: Live Weight Gain
MC: Monte Carlo Analysis
MCFs: Methane Conversion Factors
NRC: Nutrient Requirements of Beef Cattle
Scenario I: Natural grass
Scenario II: Improved natural grass
Scenario III: Natural grass/ryegrass
Scenario IV: Improved natural grass/sorghum
Scenario V: Cultivated ryegrass and sorghum
Scenario VI: Natural grass supplemented with protein mineralised salt
Scenario VII: Natural grass supplemented with protein-energetic mineralised salt
TDN: Total Digestible Nutrients
Ym: Conversion Factor