A Life Cycle Assessment Application: The Carbon Footprint of Beef in Flanders (Belgium)

Ray Jacobsen, Valerie Vandermeulen, Guido Vanhuylenbroeck and Xavier Gellynck

Abstract Although several international carbon footprint (CF) calculation initiatives have been developed, studies that focus specifically on estimating the CF of beef are rather scarce. This chapter describes the application of a CF methodology based on the lifecycle assessment of greenhouse gas emissions for Flemish beef production using the Publicly Available Specification methodology (PAS2050; BSI 2011), which is currently the most developed, profound, and relevant method for the agricultural and horticultural sectors. Both primary and secondary data were used to model the meat system by means of a chain approach. The results, which are reported using the functional unit of 1 kg deboned meat, range from 22.2 to 25.4 kg CO_2 eq/kg of deboned beef meat. A sensitivity analysis on changes in herd and feed characteristics was conducted. Results were compared to other studies on the CF of beef in the EU and other livestock produce. Three major hotspots in the CF were revealed: rumen fermentation, the composition and production of feed, and manure production and usage, which contribute a lot to the overall CF. The CF is a good indicator of greenhouse gas emissions; however, it is not an indicator of the overall environmental impact of a product. This chapter helps to fill the void in CF literature that existed around beef products and to define a benchmark for the CF.

Keywords Beef · Carbon footprint · Greenhouse gases · LCA · Hotspots · Sustainability

R. Jacobsen (✉) · V. Vandermeulen · G. Vanhuylenbroeck · X. Gellynck
Department of Agricultural Economics, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Gent, Belgium
e-mail: Ray.Jacobsen@ugent.be

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1 Introduction

Meat forms a huge part of the human diet in many European countries (van Wezemael 2011). However, the livestock production that is needed to produce meat leads to substantial greenhouse gas (GHG) emissions, causing climate change effects (Johnson et al. 2007). Livestock production causes half of all GHG emissions related to the European diet (Kramer et al. 1999; European Commission 2009). Achieving sustainable development can therefore be established by limiting agricultural GHG emissions in order to reach a stabilization of GHG emissions (Dalgaard et al. 2011).

Achieving sustainable production hence proves the need for evaluating the current situation and assessing where the production system needs improvements (Eriksson et al. 2005). If one wants to identify where along the production chain improvements can be made, it is necessary to quantify all emissions during the lifecycle. Carbon footprinting is one of the methods able to calculate the climate change impact of livestock products (Espinoza-Orias et al. 2011). A carbon footprint (CF) quantifies the climate change impact of an activity, product, or service. Within the CF, all GHG emissions (carbon dioxide [CO_2], methane [CH_4], and nitrous oxide [N_2O]) are combined. It is a measure of the total amount of GHG emissions of a system or activity, considering all relevant sources, sinks, and storage within the spatial and temporal boundary of the population, system, or activity of interest. A CF is calculated as carbon dioxide equivalent using the relevant 100-year global warming potential (GWP100) (Wright et al. 2011).

Given the importance of beef in terms of world consumption and livestock production, a study was ordered by the Flemish Government to calculate the CF of Flemish beef production in order to benchmark with other countries. Moreover, beef is an interesting case to examine for the reason that beef is increasingly imported from Latin America to Europe; in addition, estimations for the CF of beef are not readily available, especially when compared with carbon footprint studies on milk (Blonk et al. 2008b; Muller-Lindenlauf et al. 2010; Sonesson et al. 2009; Thoma et al. 2010; Van Der Werf et al. 2009).

Most studies on CF are not clear in terms of methodology or standards for either the chosen system boundaries or system definition. Stakeholders with different backgrounds and interests might draw incorrect conclusions. Indeed, different approaches in methodology prevent fair comparisons of carbon footprints between products and sectors, for the reason that different calculations are used; hence, one compares apples and oranges. A carbon footprint is calculated by means of a life cycle assessment (LCA) (Finkbeiner 2009). The fact that each LCA has to deal with many different issues (e.g., allocation method, scope, system boundaries, data, inclusion of land use change; Finkbeiner 2009) makes it necessary that each of these aspects be described in a proper way. In our own study on CF methodology applied to livestock produce in Flanders (2011), a literature study was conducted on the state of the art in terms of existing LCA or CF studies on pig production; we found that important information was missing in several cases (e.g., Dalgaard et al. 2007 and Leip et al. 2010 did not indicate the used allocation method). This problem was also mentioned by de Vries and de Boer (2010), who had to exclude sources from their meta-analysis due to a lack of data.

2 Background

The results of this chapter were obtained through a study conducted for the Flemish government in the Department of Agriculture and Fisheries. The purpose was to estimate the CF and furthermore identify hotspots in the life cycle of beef, pig meat, and milk production in Flanders. However, this article focuses solely on beef production. In Flanders, the environmental pressure from livestock production abounds, with a major impact on climate change by large emissions of GHGs.

Flemish farmers hold a total of 262,280 beef cattle per year. The beef cattle are distributed over 5,544 farms (Statistics Belgium 2010). Approximately 80 % of the farms specialize in beef production. The remaining farms produce a combination of crops and beef. Given the fact that specialized farms abound, we opted to focus on this type of farms for data collection and monitoring.

3 Methodology

3.1 Standards and Methods Used

A carbon footprint quantifies the total amount of GHG emissions for which a product, organization, or product is responsible. It is a measure of the contribution of persons, products, and organizations on the greenhouse gas effect. Figure 1 presents the different steps that occur when calculating a carbon footprint.

An LCA is used as starting point. LCA is a method to determine the total environmental impact of a product during the whole chain or lifecycle of the product. Carbon footprinting differs from LCA in one aspect: it focuses solely on quantifying GHG emissions causing climate change. Determining the carbon footprint is hence a choice to focus on one environmental indicator.

A product CF comprises all emissions related to each phase of the product's lifecycle, from cradle to grave. In practice, the boundaries of carbon footprint calculations are often shortened. The choice of the system boundaries depends upon the goal and application.

For this study, we made use of the Intergovernmental Panel on Climate Change (IPCC 2006a) guidelines in line with the National Inventory Report of Belgium (VMM et al. 2011). Although the IPCC (2006b) directive gives a description of the calculation of the total amount of GHG emissions, it does not include the allocation of GHG emissions to a particular product. In order to tackle this, a specific

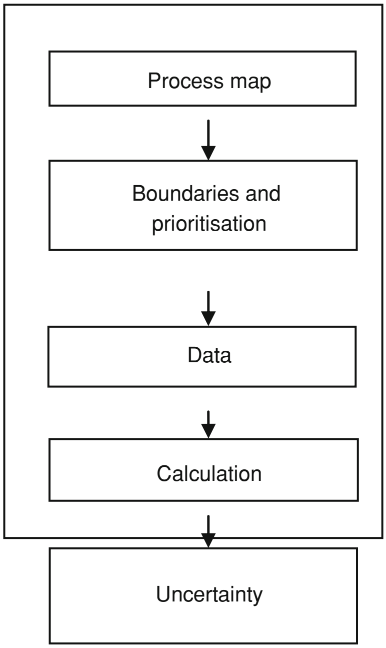

Fig. 1 The five necessary steps for calculating a carbon footprint (*Source* PAS 2050:2088; BSI)

methodology, such as the Publicly Available Specification (PAS) 2050, is needed (Espinoza-Orias et al. 2011). PAS2050 (BSI 2011) was chosen because it is one of the most profound methods available (among others; e.g. ISO 14067). In 2012, specific Product Category Rules (PCR) were developed according to the international Environmental Product Declaration (EPD) system (Environdec 2013) for mammal meat, including beef, in which slaughter activities, packaging processes, and storage are the core processes (Studio LCE 2012); hence, these were used as core activities in our study.

Based on the IPCC 2007 (IPCC, AR4, 2007), the global warming potentials (GWP) for methane and nitrogen gas emissions are defined as follows: 1 kg of methane (CH_4) equals 25 kg of CO_2 and 1 kg of nitrogen gas (N_2O) equals 298 kg CO_2.

3.2 Scope and System Boundaries

PAS2050 states that emission factors contributing <1 % of the total CF are negligible (BSI 2011). The lion's share of GHG emissions occur at farm level. Therefore, the ultimate steps in the beef chain (Blonk et al. 2008b; Campens et al. 2010) are not included in the calculations of the CF. Table 1 gives an overview of the included emission sources throughout the chain.

Table 1 Overview of emission sources within the covered system boundaries

Name	GHG	Description
Feed mixtures (purchased)	CO_2 and N_2O	Farming, transport, processing, and land conversion included
Animal	CH_4	IPCC method (Tier 2)
Manure storage and disposal	CH_4 and N_2O	IPCC method (Tier 2)
Manure application (not used for own feed mixtures)	CH_4 and N_2O	Allocation between animal (40 %) and vegetable production system (60 %) based on nitrogen uptake by plants
Energy and water consumption	CO_2, CH_4 and N_2O	Energy consumption (electricity, [red] diesel, gas); water consumption (tap and ground water)
Transport of goods	CO_2, CH_4 and N_2O	Assumptions made for the goods entering and leaving the farm
Processing materials	CO_2, refrigerant	Cleansing products, refrigerants

The study included the GHG emissions shown in Fig. 2. Production of materials, energy, and transport steps are included. The system boundary excludes production of capital goods, similar to most international studies.

3.3 Functional Units

Several functional units were defined upon agreement of the guiding committee of the project. This allowed better identification of the hot spots along the beef production chain. The functional units used were 1 kg of live beef meat, 1 kg of beef after slaughtering, and 1 kg of deboned beef meat.

3.4 Allocation Method

Another very important assumption describes the allocation of GHG emissions between the various byproducts emerging from a process. There are two major ways of allocation: physical and economic allocation. With regards to the project, a combination of both methods was applied, depending upon the chain stage. In terms of the slaughtering and deboning process, economic allocation was used: the economic value of the byproducts (bones, fat, skin, hide, heart, blood, etc.) represents the market prices multiplied by the mass fraction per incoming product (if it is a cost, then allocation share is zero). Manure contributes to the production of crops; therefore, physical allocation was used in order to allocate the GHGs from manure among crops and animal production. Overall, a combination of physical and economic allocation based upon several other references was used (Blonk et al. 2008a).

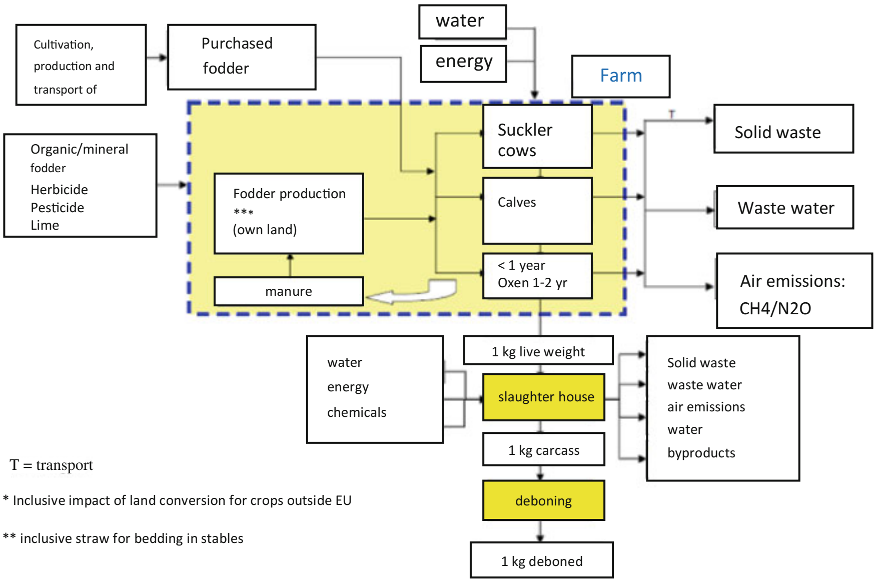

Fig. 2 The system boundaries. The boxes with *dashed lines* present a process; *solid lines* indicate a product flow. The *colored boxes* are the foreground system

3.5 *Land Use and Land Use Change*

According to the PAS2050 methodology, land use change (LUC) should be considered if land conversion took place in the last 20 years. This is not the case for agriculture in the EU; thus, LUC is zero. However, part of the feed is imported overseas; for those, FAO (2010) are used to define the LUC in the past 20 years. The total emissions from this LUC are calculated and 1/20th is attributed to each forthcoming year (Blonk et al. 2008a; Ecoinvent 2011; Nielsen et al. 2010).

Land use as such (or carbon sequestration in the soil) is not considered in the calculations. In Flanders, considerable uncertainty remains with regard to the net effect (absorption or emissions) from land use; therefore, it was not included. International standards and guidelines for carbon footprinting also exclude it from the necessary calculations (ERM 2010).

4 Data Sources

PAS2050 has specific rules for using primary data over secondary data (BSI 2011). Primary data were complemented with secondary data and reports from umbrella organizations. Data were collected for 2009. However, certain data required more recent values, such as the feed compound composition, which changes daily.

Table 2 Yearly consumption of feed compound per beef cattle farm

Resources	Product (kg)	Yield[a] (kg product/ha)
Soy meal[b]	1,300	
Sugar beet pulp (dry)	910	
Sugar beet pulp (wet)	72.800	
Wet byproducts	27.430	
Milk powder	845	
Single forage	91	
Composite forage	69.680	
Grass silage and fresh grass (homegrown)	1.044.500	22.389[c]
Maize (homegrown)	359.800	48.670
Fodder beets (homegrown)	1.764	98.470

[a] Homegrown
[b] Origin of imported soy: 53 % Brazil, 11 % Argentina, 21 % United States, and 16 % Canada
[c] Weighted average meadow/temporary grassland

4.1 Raw Materials and Farm Level

The data on the representative conventional farm were collected through the Farmers Union dataset (Boerenbond 2011). This dataset was used to select the farms specializing in beef production. Flanders has 4,334 specialized beef cattle farms (NIR Belgium).

The database allowed identification of the average of the data to obtain a representative and existing farm. Outliers in the data were not used. Hence, the average represents a real farm with the following characteristics:

- 53 calves <12 months,
- 47 young cattle 1–2 years,
- 65 suckler cows.

Farms are confronted with the loss of animals. The mortality rate amounts to 1.25 % for mature animals and 11 % for calves. The replacement rate amounts to 34 %.

Data on manure production were collected from reports of the Flemish Centre for Manure processing and were linked to the number of animals on the farm (VLM 2011).

The fodder applied partly originates from the farm's own production and is partly purchased. Table 2 presents the overview per farm. The average composition of the feed concentrate was given by the Belgian Feed Compound Union (BEMEFA; personal communications, April–October 2011). The composition of the feed compound was given for October 4, 2010, which was randomly chosen during the course of the project. It varies daily according to the availability of components on the market. One can be sure that the feed used has an appropriate composition for the animals.

Emission factors were derived from BlonkMilieuadvies (Blonk et al. 2008a); Nielsen et al. (2010); and Ecoinvent (2011).

A suckler cow consumes the following raw feed components (homegrown) per year: 8.053 kg of grass, 7.697 kg of feed corn, and 636 kg of other raw feed components (mainly fodder beets). This is extended with purchased fodder consisting of 1.120 wet sugar beet pulp, 1.072 kg composite feed concentrate (see Table 2), 422 kg wet byproducts, 140 kg single forage, 20 kg soy meal, and 14 kg sugar beet pulp per suckler cow per year, as well as 13 kg milk powder.

The animals are kept in stables on a bed of homegrown straw. Suckler cows and female young cattle (1–2 years) stay outside for 24 h a day, during a period of 6 months/year. Female calves remain outside for 24 h a day, during a period of about 4 months. The male young cattle and the male calves stay inside. The animals produce 623 kg of manure per day. Approximately 32 % of this manure ends on the grassland during grazing, 60 % is preserved as stable, and 8 % as mixed manure.

The farmer possesses 48 ha of grass and cropland: 22.6 ha grassland, 10.3 ha of maize, 0.7 ha temporary grassland, 0.5 other roughage, and 13.9 ha of wheat. Fertilizer use consists of 650 kg of fertilizer per hectare of grassland (with 170 units of nitrogen) and 100 kg of starter fertilizer per hectare of maize (20 units of nitrogen and 2 units of phosphorus). The farm uses on average 2.65 kg of herbicides and 500 kg of lime, both per hectare.

The farm annually consumes 8.637 kWh of electricity and 8.054 L of oil fuel. In terms of water consumption, the farm consumes 773 m^3 of ground and 243 m^3 of tap water.

4.2 Meat Processing

The contacted slaughterhouses ($N = 4$) represented 33 % (weight) of processed beef in Flanders and hence were representative of the whole sector. Data were collected on meat weight and prices, byproducts and carcass, energy consumption, and transportation characteristics.

Missing data, such as the price of cuts and amount of waste/meat generated through slaughtering, were given by the Flemish Meat Federation (Febev).

5 Data Analysis

5.1 Emissions from Fodder Production

A distinction was made between homegrown and purchased fodder. The production of fodder also comprises the production and transportation of resources to sow, grow, and harvest the crops (seeds, fertilizers, pesticides, and diesel). The accompanying emissions are allocated to the crops. Land use during cultivation of

Table 3 Composition of feed concentrate for beef cattle. Allmash 16 is a commercial feed compound name

Resources	Beef cattle ALLMASH 16 (share in %)
Barley	12.5
Soy meal	5
Maize yellow from France	5.9
Maize gluten feed	22.5
Sugarbeet pulp	20
Linseed flakes	12.5
Rapeseed flakes	8.3

Source BEMEFA

the crops results in extra GHG emissions. Laughing gas is the most important greenhouse gas for land use.

For purchased fodder, crops are being transported to a processing plant. Emissions accompanying transport and processing are included. A 50/50 ratio for male and female for the young cattle and calves population is assumed.

5.1.1 Purchased Fodder

The resources of composed concentrate are processed to fodder consisting of different components. The BEMEFA was contacted to identify the composition. Databases were consulted on August 4, 2011; furthermore, feed specialists were consulted. Table 3 indicates the representative composition of approximately 80 % of feed concentrate for beef cattle.

The applied emission factors are derived from literature (Blonk Milieu Advies, University Wageningen). The available data were extended with other sources: the Ecoinvent database, LCA food database, and Carbon Trust. Table 4 presents the emission factors for the purchased fodder.

5.1.2 Homegrown Roughage

Farm land is applicable as grassland and moreover for the cultivation of fodder crops. The yield of the own crops is used as roughage. Table 5 presents the calculated emissions.

Energy and fuels used for machinery and transportation are included for the total energy consumption of the farm. They are not mentioned in Table 5. GHG emissions accompanying production and transportation of fertilizers, herbicides, insecticides, and fungicides are also included. Emission factors were calculated from the Eco-invent database. Emissions due to the application of these substances are mentioned in Table 6.

Table 4 Emissions accompanying purchased fodder per kilogram of product

Resources	kg CO_2 eq/kg product	Land use change (%)
Soy meal	3.06	71
Sugar beet pulp (dry)	0.11	
Sugar beet pulp (wet)	0.03	
Wet byproducts	0.03	
Milk powder	7.9	
Single forage	0.30	
Composite forage	0.42	19.8

Table 5 Emissions accompanying the cultivation of own crops

Resources	Area (ha)	kg CO_2 eq/year
Wheat (homegrown) for straw	13.9	17.659
Maize (homegrown)	10.3	32.150
Grass silage	23.3	23.9408
Fodder beets (homegrown)	0.5	4.989

Table 6 Emission factors: production, transportation of fertilizers, herbicides, and lime

Name	Value	Unit
Fertilizer (calcium ammonium nitrate)	8.81	kg CO_2 eq/kg N
Herbicide	10.730	kg CO_2 eq/kg
Lime (calcium carbonate)	0.02	kg CO_2 eq/kg

Laughing Gas Emissions
N_2O emissions due to crop cultivation are calculated according the IPCC 2006a, b, c method. Nitrogen sources applied to land are in this case fertilizers, natural fertilizers, and crop residue.

Direct laughing gas emissions are the result of denitrification. It is assumed that 1 % of all nitrogen applied to land converts to laughing gas (uncertainty interval 0.3–3 %). The IPCC value (1.25 %) was still applied in the national inventories until 2013. Current research in Flanders points out that 3.16 % of all nitrogen converts to N_2O. *Indirect* laughing gas emissions due to nitrogen leaching are calculated with data recorded in the National Inventory Report for greenhouse gases (NIR) of Belgium (2009). The amount of nitrogen leaching was determined with the Systems for the Evaluation of Nutrient Transport to Water model. In Flanders, 9 % of all applied nitrogen is leaching (NIR 2010, H6, p. 120). Of this, 0.75 % is finally converted to N_2O (IPCC 2006a, b, c). Indirect N_2O emissions due to nitrogen evaporation as ammonia (NH_3) and NO_x are calculated with the same data from the NIR Belgium (2009). The amount of evaporated nitrogen as NH_3 or NO_x, depends upon the nitrogen source:

Table 7 Emission factors electricity and gasoline oil

Name	Value	Unit	Source
Electricity	0.40	kg CO_2 eq/kWh	Energy covenant
Gasoline oil	2.66	kg CO_2 eq/kg	Energy covenant

(1) *Fertilizer* in Flanders: average NH_3 evaporation amounts to 3.3 % and the NO_x evaporation amounts to 1.5 % (NIR 2010).
(2) *Organic fertilizers* in Flanders: average nitrogen evaporation as NH_3 or NO_x amounts to 20 % (NIR 2009).

According to the IPCC calculation method, 1 % (0.2–5 %) of evaporated nitrogen (as NH_3 or NO_x) is converted to N_2O.
Lime Application
Lime is applied on land to increase the soil pH. This causes CO_2 emissions. For beef cattle farms, the total amount of lime applied per year is 1000 kg. The used emission factor is 0.48 kg CO_2 eq/kg lime (e.g. dolomite).

5.2 *Emissions from Cattle Breeding*

5.2.1 Energy Consumption Farm

The energy consumption is included as a whole and not allocated. In Table 7, emission factors are presented. Each suckler cow annually consumes about 1.512 kWh (10 % electricity and 90 % gasoline oil).

5.2.2 Animal Emissions: Rumen Fermentation

Emissions due to rumen fermentation are calculated based upon the IPCC guidelines (Tier 2 method). For calculating the necessary gross energy uptake (GE) per animal, the daily need, growth, and gestation is included. It is assumed that suckler cows produce a negligible amount of milk. The digestible energy (DE) is expressed as %GE. An adapted value is calculated based upon the fodder and the number of grazing days. It is calculated that approximately 169 MJ of GE is needed per suckler cow, 121 MJ for young cattle, and 82 MJ for calves. The digestible energy is calculated to be on average 74 %GE based upon the fodder. Table 8 represents the digestible energy per feed component. The time spent on grassland is included in order to determine an adapted digestible energy content of the animals' diet.

Approximately 6.5 % (weight basis) of the taken gross energy is converted to gas (methane) (IPCC 2006a). If the animals are fed more than 90 % with composite fodder, the above number can be lowered to 3 %. The taken gross energy is

Table 8 Digestible energy value for different types of fodder

Name	DE	Unit	Source
Wheat/barley	86	%GE	FAO
Maize/roughage	72	%GE	NIR Belgium
Soy meal	80	%GE	FAO
Beet pulp/citrus pulp	81	%GE	FAO
Wet byproducts	78	%GE	FAO
Composite fodder	80	%GE	NIR Belgium
Protein, vitamins	80	%GE	Proxy: composite fodder
Feed concentrate	80	%GE	Proxy: composite fodder
Composite young feed	80	%GE	Proxy: composite fodder
Fodder for young cattle	80	%GE	Proxy: composite fodder
Full milk	90	%GE	NIR Belgium
Grass silage	72	%GE	NIR Belgium
Fresh grass (grazing)	79	%GE	NIR Belgium

* Greenhouse gas emissions from the dairy sector: a Life Cycle Assessment 2010
Source FAO* and NIR Belgium

calculated based upon the fodder composition and the digestible energy content of each feed component.

5.3 Emissions Manure Storage and Usage

Manure production takes place on the meadow and in the barn. Suckler cows stay approximately 183 days/year on the meadow, female young cattle (between 1 and 2 years) also stay 183 days/year, and female calves (<1 year) stay approximately 122 days. Male young cattle and male calves are not put on the meadow. Manure produced in the stable is stored temporarily. It is assumed that 80 % of the manure production in the stable is being stored as stable manure. Manure disposal on grassland and manure storage are accompanied with methane and N_2O emissions. The calculations are explained below, based upon the IPCC 2006a, b, c guidelines (Tier 2).

5.3.1 Methane

Methane emissions related to manure production depend on the excreted volatile solids, the maximum methane production capacity of the manure, and the storage. The excreted volatile solids are calculated by using the IPCC (2006a) formula. Moreover, the IPCC 2006a, b, c reference value for the urine fraction (4 %) and dry matter content (8 %) were used (IPCC 2006b). Allocation of manure production between meadow and stable is presented in Table 9.

Table 9 Methane conversion factors and manure storage systems

Name	Stable manure (%)	Mixed manure (%)	Manure disposal on grassland (%)
Methane conversion factors	2	19	1
Manure suckler cows	40	10	50
Manure young cattle (1–2 years)	60	15	25
Manure calves (<1 year)	83		17

Source IPCC, NIR Belgium, Farmer's union

Table 10 N_{ex} per type of animal

Animal category	N_{ex} (kg/head.yr)
Calves (<1 year)	33
Young cattle (1–2 year)	58
Suckler cows	65

Source NIR Belgium/manure database

5.3.2 Laughing Gas

Through a combination of nitrification and denitrification, N_2O is released from stored manure or was disposed on land. The amount of produced laughing gas emissions depends upon the nitrogen excretion of the animals (N_{ex}). The excreted nitrogen per type of animal is taken from the NIR report of Belgium (Table 6.12).

The amount of N_2O from the total amount of nitrogen depends upon the manure storage. It is assumed that 0.5 % of total nitrogen is converted to N_2O during manure storage. For mixed manure stored underneath the slatted floor, it is assumed 0.1 % of the total nitrogen is converted to N_2O during storage. For manure disposed on the meadow by the animals, a 2 % conversion to N_2O is assumed (*direct emissions*) (Table 10).

Indirectly, there are N_2O emissions formed through volatilized NH_3 and NO_x. The amount of NH_3 and NO_x formed from the manure depends upon storage. Table 11 presents how much of the total nitrogen converts to NH_3 and NO_x. It is assumed that 1 % of indirect nitrogen losses converts to laughing gas (*indirect laughing gas emissions*).

5.3.3 Manure Usage for Crop Production

When manure is used on agricultural land for growing crops, emissions are allocated among crops and livestock. All produced manure is disposed of on the farm's own land. Accompanying emissions are described in Sect. 5.1.

Table 11 Nitrogen losses from manure as NH_3 or NO_x as a function of manure storage systems (IPCC 2006a, b, c)

Name	Nitrogen volatilization (NH_3/NO_x) (%)
Beef cattle—stable manure (fixed manure)	45
Beef cattle—mixed manure storage	40
Beef cattle—manure disposal on grassland	20

5.4 Emissions from Transport

Feed components are transported to the processing plant. Distances are limited within Europe. The soy component is transported overseas. Emissions related to both types of components are included in the applied emission factors and covered by the production of purchased fodder. For homegrown roughage, the necessary amount of fuel in the total energy consumption (Sect. 5.2.1) is included.

Feed is transported from the fodder processing plant to the farm (average distance of 30 km). The related emissions are covered within the farm data.

Cattle are transported from farm to slaughterhouse (average distance amounts 25 km).

5.5 Emissions from Meat Processing

Emissions originating from slaughtering are related to electricity consumption, fuel, cleansing products, water usage, and waste processing. Other transport methods are included as well. Emission factors are derived from Table 7 and the Ecoinvent (2011).

Furthermore, emissions are allocated to meat and other useful byproducts. Economic allocation is used at the slaughtering and deboning phase. The carcass yield is 67 % and the meat yield on carcass is 81 % for the Belgian White-Blue race.

6 Results

6.1 The CF of Beef

Results are presented in Fig. 3. In summary, 1 kg of deboned beef meat creates a *CF* of 22.2 kg CO_2 eq. Rumen fermentation, homegrown crops cultivation, and manure production and usage have the lion's share in the overall CF. The slaughtering process contributes 0.01 % of the total CF.

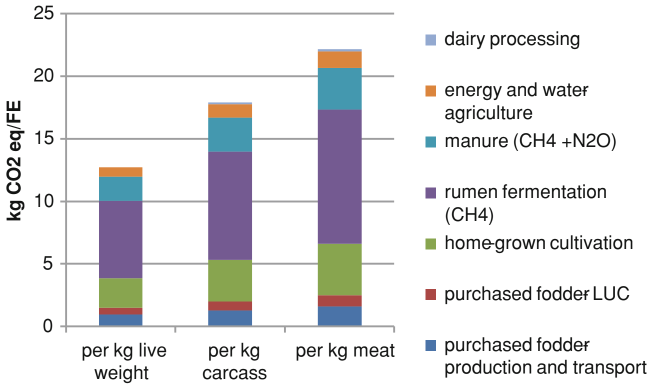

Fig. 3 The carbon footprint of 1 kg of beef in Flanders

The carbon footprint of live weight is 12.7 kg CO_2 equivalents. At the farm level, rumen fermentation represents 48.8 % of the carbon footprint, strongly determined by the feed uptake and digestibility. Feed consumption is estimated with available data; however, the reference values for digestibility are accompanied with a high uncertainty.

Fodder production is responsible for 29.5 % of the CF. Although only 13 % of the fodder is purchased, the impact is only 50 % compared to homegrown crop cultivation. The total impact of LUC contributes for 4 %. Manure storage and application on grassland contribute 15.3 % of the emissions (19 % is due to methane and 81 % due to N_2O emissions). Energy represents 5.9 % of this impact, electricity consumption represents 13.8 %, gasoline oil is 86 %, and water is 0.2 %.

At the slaughterhouse and deboning level, an extra 0.15 kg CO_2 eq/kg of carcass is added. The largest contribution (52.7 %) relates to waste management of the byproducts. Energy consumption contributes 37.5 %. Of this, 75 % is due to electricity consumption. The remaining 25 % is due to the combustion of fossil fuels. Furthermore, animal transport between the farm and slaughterhouse is 9.7 %. The production of process materials is negligible.

6.2 *CF Sensitivity*

The single outcome of CF calculations should be used with caution. A range of figures in which the CF is expected to be provides a more realistic insight (Flysjo et al. 2011b). Therefore, a sensitivity analysis[1] is conducted to define fluctuations.

[1] A statistical sensitivity analysis was not carried out because not enough information was available to calculate the standard deviation on the secondary data used or on the final result.

Table 12 Applied sensitivity analysis: impact of changes in herd and feed concentrate parameters on the CF

Parameter	Initial value	Min	Shift in CF	Max	Shift in CF
Mortality rate of animals <1 year	11 %	5 %	−0.6	15 %	+0.50
Moratlity rate of animals >1 year	1.25 %	0.5 %	−0.05	3 %	+0.1
Calving interval	365	–[a]	–	420	+2
Final weight bull/cow	680/690	660/670	+0.25	700/720	−0.3
Digestible energy content of fodder (%GE)	76 %	66 %	+1.9	86 %	−1.2

[a] The initial calving interval could not be lowered

6.2.1 Feed and Herd Characteristics

Table 12 presents trends in feed and herd characteristics and their possible impacts on the CF.

When the mortality rate for animals <1 year is decreased from 11 to 5 %, the CF decreases with 0.6 kg CO_2 eq/kg of deboned meat. Greater effects are identified for the rise in value for the GE from 76 to 86 %, leading to a CF fall of 1.2 kg CO_2 eq/kg of deboned meat and a decrease from 76 to 66 %GE, leading to CF rise of 1.9 kg CO_2 eq. Finally, a switch in the final weight also has an impact. Changing it from 680 to 700 decreases the CF with 0.3 kg CO_2 eq/kg of deboned meat, whereas a decrease in weight to 660 kg increases CF with 1.9 kg CO_2 eq.

6.2.2 Manure Storage/Disposal

An allocation between manure disposal on grassland (59 %) and in the barn is defined. For the latter, part of the manure is stored as barn manure (8 %) and the other as mixed manure (33 %). In total, three scenarios are considered. It is assumed that 100 % of the manure production is disposed on grassland (scenario 1), as barn manure (scenario 2), or stored as mixed manure (scenario 3) (Table 13).

The results are little influenced by these parameters. Storage as stable manure provides the least emissions. With extended time on grassland, animals consume more energy. The calculated gross energy is higher—hence, the rumen fermentation.

6.2.3 Influence of Allocation Method

Byproducts emerge in the slaughterhouse and deboning facility. Economic allocation was chosen because this method takes into account the value of the products. An alternative allocation method is based upon mass.

Table 13 Variation on parameters regarding manure storage

Parameter	Initial value	Scenario 1	Scenario 2	Scenario 3
Disposal grassland (%)	59	100	0	0
Stable manure (%)	8	0	100	0
Mixed manure (%)	33	0	0	100
Result (relative towards initial)	1	1.01	0.97	1.02

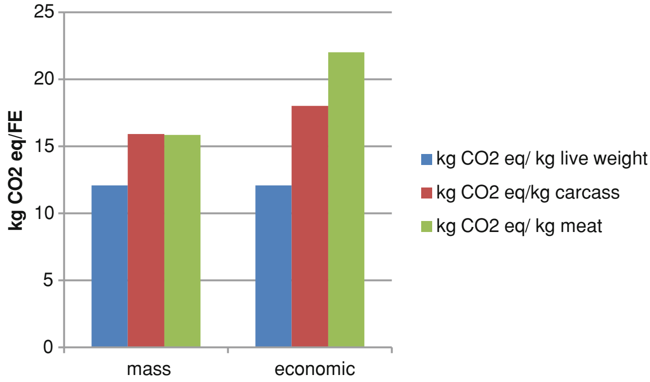

Fig. 4 Sensitivity of allocation method for beef meat

Figure 4 presents the impact of using different allocation methods on the overall CF.

The final calculated carbon footprint per kilogram of carcass and meat is significantly lower when one applies mass allocation. More emissions have to be allocated to other animal parts. It is therefore clear that there is no such thing as a single value for the CF. A range of values should always be given when the CF is reported, due to uncertainties and variations given the biological nature of the product.

6.2.4 CF Range

Based upon this sensitivity analysis, the overall estimated CF of beef production in Flanders falls between the range of 22.2 and 25.4 kg CO_2 eq/kg of deboned meat. For live weight, the carbon footprint ranges between 11.6 and 14.6 kg CO_2 eq/kg live weight; for carcass, the CF ranges between 16.3 and 20.5 kg CO_2 eq/kg carcass. Live weight obviously has the lowest carbon footprint because the deboning processes did not take place yet. The further down the beef production chain, the higher the carbon footprint.

Table 14 Comparison of the carbon footprint of Flemish beef with other international values

Study	Result (kg CO_2 eq)	Functional unit
Williams (2006)	16	1 kg carcass
Blonk et al. (2008a, b)	15.9	1 kg meat
Cederberg et al. (2009)	22.3	1 kg organic Swedish beef
Cederberg et al. (2009)	36.4	1 kg Japanese Kobe beef
Cederberg et al. (2009)	22	1 kg American beef
Own analysis	16.3–20.5	1 kg carcass
Own analysis	22.2–25.4	1 kg deboned meat

7 Discussion

7.1 Relative Importance

Comparing the CF of beef in Flanders with other international studies is not straightforward due to the different choices made. Table 14 makes a comparison.

Some authors report findings of a similar CF for beef, whereas others report a lower or higher CF. Williams (2006) reported a carbon footprint of 16 kg CO_2 eq/kg of carcass, which is a bit lower than the range being reported. Blonk et al. (2008a, b) studied the greenhouse gas emissions of meat (production). Their result is somewhat lower than our calculations. Cederberg et al. (2009) report somewhat higher CFs.

Next, the CF of beef can be compared with the CF for pigmeat and milk production. Within the same study, it is shown that the CF of pigmeat produced in Flanders lies between 3.1 and 6.4 CO_2 eq/kg of deboned pigmeat and of milk between 1.03 and 1.36 kg CO_2 eq/kg of milk consumed (1.5 % fat).

7.2 Mitigation Measures

Three huge hotspots in the production of beef meat were revealed: rumen fermentation, fodder production, manure production, and the usage of it. Some opportunities to reduce the CF of beef were defined.

In particular, the composition of feed has a very big impact on the overall CF. Within Europe, the use of soybean in feed concentrates has increased rapidly. However, the use of soy has a negative impact on the CF (negative LUC impact and transportation of feed components over long distances; Hortenhuber et al. 2011). Therefore, replacement with regional products can reduce the CF. When overseas products are to some extent indispensable, priority should be given to products produced in a sustainable way with a restricted impact on LUC. However, the composition of the feed depends more on availability, price, and the characteristics of the components. Price and availability are major economic factors influencing the final price of the feed and the possible usage by farmers. Hortenhuber et al.

(2011) clearly indicated that regional and local products are not always at people's disposal. Shifting production in Europe towards these alternatives might lead to LUC effects in Europe (Steinfeld et al. 2006). However, one cannot remove all carbon-negative components because this limits the economic sustainability of farming practices.

Therefore, parameters such as price, availability, and feed component characteristics need to be taken into account alongside the CF to ensure that meat production is not compromised in an effort to reduce the GHG emissions (Espinoza-Orias et al. 2011). This economic aspect is often neglected in other literature, as described by Verspecht et al. (2012). Manure production, storage, management, and usage is the second largest contributor to the overall CF. In Flanders, the most popular method of manure management involves separation of liquid and solid components of manure. The solid part gives rise to a similar quantity of nitrate emissions as the storage and use of untreated animal manure would do.

Both things exemplify the possible tradeoffs between dealing with GHG emissions and other aspects of sustainability, put in a larger perspective. Sustainability consists of three pillars: environmental protection, economic growth, and social equity. A mitigation measure only has a positive affect when all aspects lead to better or higher sustainability. Moreover, it is important to stress that the CF is a good indicator for GHG emissions as one environmental indicator, but it is not an indicator for environmental impact in general.

8 Conclusion

The CF of beef estimated in our study using the PAS 2050 methodology (BSI 2011) ranges from 22.2 to 25.4 kg CO_2 eq/kg of deboned beef meat. The main hotspots were found in rumen fermentation and fodder production, accounting for the greatest proportion of the total CF. Furthermore, manure management is another important hotspot in the production chain. These hotspots reveal where measures can be taken in order to decrease GHG emissions along the chain. Our study helps to fill the void in CF literature that existed around meat products. Moreover, the chapter reports on the methodology and assumptions that have been used, the chosen system boundaries, and the system definition. This makes it possible to follow a similar method and estimate the CF of beef in other regions, allowing better and fairer comparisons (Flysjo et al. 2011a) and hence assisting the definition of a benchmark for the CF. This in turn will stimulate the search for opportunities to reduce the CF within the framework of international targets, such as the 2011 Durban Accord (Dalgaard et al. 2011).

Flanders is required to implement European policy measures with regard to agriculture. From this perspective, our study will assist Flemish policy makers in achieving their aims for the period 2012–2020. During this period, GHG emissions for EU sectors that do not fall under the transferable emission system have to decrease by 15 %. Therefore, this study helps to reveal hotspots in the chain and potential strategies to decrease their impact in terms of GHG emissions. However, it should be noted that an integrated sustainability approach is necessary; this study focused solely on the environmental impact of one indicator: climate change.

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