Research Article

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Carbon footprint of organic beef meat from farm to fork: a case study of short supply chain

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Abstract

BACKGROUND: Sustainability of food systems is one of the big challenges facing humanity. Local food networks, especially those using organic methods, are proliferating worldwide, and little is known about their carbon footprints. This study aims to assess greenhouse gas (GHG) emissions associated with a local organic beef supply chain using a cradle-to-grave approach.

RESULTS: The study determined an overall burden of 24.46 kg CO_2 eq. kg^{-1} of cooked meat. The breeding and fattening phase was the principal source of CO_2 in the production chain, accounting for 86% of the total emissions. Enteric methane emission was the greatest source of GHG arising directly from farming activities (47%). The consumption of meat at home was the second high point in GHG production in the chain (9%), with the cooking process being the main source within this stage (72%). Retail and slaughtering activities respectively accounted for 4.1% and 1.1% of GHG emissions for the whole supply chain.

CONCLUSION: The identification of the major sources of GHG emissions associated with organic beef produced and consumed in a local food network may stimulate debate on environmental issues among those in the network and direct them toward processes, choices and habits that reduce carbon pollution.

Keywords: organic beef meat; local food network; LCA; GHG emissions; climate change

INTRODUCTION

The production of food has been identified as one of the most important pressures on the environment.[1] The food system, considering all stages from primary production to waste disposal, contributes from 19% to 29% of global anthropogenic greenhouse gas (GHG) emissions.[2]

Food supply will be one of the major priorities for humankind in the 21st century. Human demand for animal proteins is expected to increase over the next decades due to continuous growth in world population and per capita consumption.[3] To satisfy the increasing demand for food it will be necessary to increase production, which will have a high environmental impact in terms of consumption of resources (e.g. land, water, energy) and release of pollutants into air, water and soil.[4] In this context, bovine meat production has been identified as the main source of GHG emissions among food products.[5]

Carbon footprint (CF), an indicator calculated with a life cycle assessment (LCA) approach, evaluates the GHG associated with the life cycle of a product.[6] CF considers all processes in the production of a product including raw materials, intermediate products, transport and waste disposal. Several studies have been carried out to evaluate the environmental impact of beef production considering all activities up to the farm gate,[7–9] but only few of these included the further stages such as slaughtering, processing, retailing and consumption.[10–12] These studies were mainly at country level or related to large scale retail distribution. To the best of our knowledge, no studies have been carried out to calculate GHG emissions associated with organic beef production and its consumption in a local food network. There is no clear and simple definition of 'local food network' or a 'short supply chain'.[13] Here, by 'short', we mean characterized by a short distance between producer and consumer (proximity) and that the number of intermediaries involved in the supply chain should be as few as possible.[14] The present case study is aimed at investigating the CF of organic beef meat produced and consumed within a local supply chain.

MATERIALS AND METHODS

Functional unit and system boundaries

The functional unit was 1 kg of cooked beef, including waste disposal, evaluated at the consumer's home. No distinction was made between different cuts of meat (e.g., steak, loin, or fillet).

The burdens associated with the short beef supply chain were evaluated with a 'cradle-to-grave' approach.[6] The system boundaries included the breeding and fattening of animals, slaughtering operations, meat processing including production of packaging, retail activities, transport, home storage, cooking and waste disposal. The boundary system is shown in Fig. 1.

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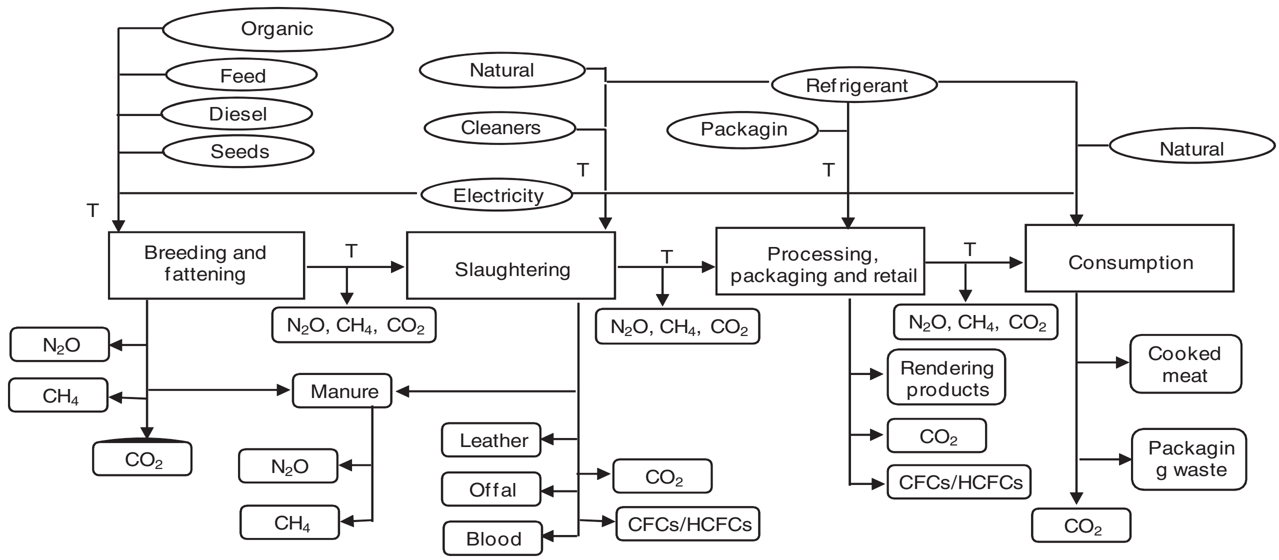

Figure 1. Analysis of system boundaries of short organic beef supply chain. T indicates the transports between and within processes.

Life cycle inventory

Data are for the year 2014 and were collected throughout the processes included in the system. Where this was not possible, data were obtained from international databases that support environmental assessments,[15] calculated using appropriate models indicated by the guidelines for national greenhouse gas inventories[16] or provided from sources in the bibliography. A summary of the data is reported in Table 1.

Breeding and fattening

We considered an organic Italian farm where cows are bred and fattened for consumption. The farm breeds native Chianina beef cattle and may be considered to represent a typical organic farming system for beef production in central Italy in terms of animals, land size and management. The Chianina breed is characterized by somatic gigantism, long trunk, lightweight skeletal structure, great ease of calving, adaptability to a variety of environments, resistance to harsh environments and modest feeding requirements. Fattened bulls were slaughtered between 20 and 24 months old and at 700 kg of live weight (LW). Farming consisted of two phases: breeding of cows and heifers for calf production and fattening of bulls. All animals were fed a total mixed ration.

The farm cultivated 106 ha, no extra feed was purchased, and organic manure (3268 t) was mechanically spread as organic fertilizer. Slaughtered animals leaving the farm refers to fattened bulls, heifers (those not used for breeding) and culled cows; no distinction was made between these types of meat.

Slaughtering, retail and consumption

All animals were slaughtered in the same abattoir 33 km from the farm. The abattoir received different livestock species and a total of 25 601 animals were slaughtered in 2014, including: 3304 cattle, 8923 pigs and 13 374 lambs. The primary products were meat carcasses, with offal, blood and leather as co-products. The carcasses are usually stored at 0–2 °C for 2 days at the plant and then transported to retail outlets for aging and processing operations. The storage system at the plant used 180 kg R-434a (a refrigerant gas blended from pentafluoroethane, tetrafluoroethane, triflouroethane and isobutane).

Table 1. Data from 2014 collected throughout the supply chain

Process Categories of input	Data
Breeding and fattening	
Seeds	7.4 t
Land use	106 ha
Organic fertilizers	3268 t
Cows	71
Bulls	2
Calves (0–6 months)	58
Heifers for breeding (6–24 months)	23
Growing bulls (6–12 months)	19
Fattening bulls (12–24 months)	33
Average slaughter weight	700 kg
Slaughtered bulls/year	31
Slaughtered cows/year	6
Fuel	21 684 L
Electricity	56 059 kWh
Slaughter house	
Animals transported to plant[a]	2442 km
Natural gas	37 060 kg
Electricity	292 433 kWh
Refrigerant gas	180 kg
Butcher's shop	
Transport of input	4584 km
Beef sold	9536.7 kg
Electricity	11 319 kWh
Refrigerant gas	5.6 kg

[a] The total distance was calculated considering 37 animals leaving the farm, 33 km from farm to slaughterhouse and a round-trip journey.

Transport of cattle from farm to plant, energy consumption (electricity and methane), refrigerant gas leakage, manure produced by animals waiting to be slaughtered, cleaners and bullets used for captive bolt were considered for the slaughtering operations.

The butcher's shop received beef only from the farm considered (farm butcher's shop). The transport of beef carcasses from

Table 2. Main findings from the interviews aimed at collecting information on consumer practices in shopping for and consuming meat (average values)

Phases Practice[a]	Data
Meat purchased	
Quantity for each shopping trip/customer	2 kg
Bovine	72%
Others	28%
Meat transported	
On foot	17%
By car	83%
Diesel	64%
Petrol	28%
NGV[b]	8%
Distance travelled for each shopping/customer	10 km
Meat stored	
Refrigerator	20%
Freezer	80%
Time in refrigerator	2 days
Time in freezer	21 days
Meat cooked	
Gas stove	89%
Electric oven	11%
Packaging disposal	
Recycled	44%
Not recycled	56%

[a] Consumer practices acquired from interviews with a sample (50) of butcher's shop customers.
[b] Natural gas vehicle.

slaughterhouse to butcher's shop, electricity consumption, refrigerant gas leaks and packaging production were accounted for in the retail activities.

The storage system at the butcher's shop consisted of a climate-controlled chamber for meat aging and a refrigerated bench for meat exhibition that used a total of 5.64 kg of R-404a (a refrigerant gas blended from pentafluoroethane, trifluoroethane and tetrafluoroethane) and 0.4 kg of R-134a (tetrafluoroethane).

Total meat sold at the butcher's shop was 13 176 kg year^{-1}, which included: 9536 kg of beef, 1938 kg of pork, 1049 kg of lamb, 574 kg of chicken and 76 kg of rabbit. The packaging for 1 kg of meat consisted of two sheets, one made of 19 g of paper and 1 g of low-density polyethylene (LDPE), and the other made of 2 g of high-density polyethylene (HDPE). Customers usually had their own shopping bags and therefore these were not considered in the study.

A sample of 50 customers was interviewed to acquire data for the analysis of meat consumption. Data acquired with the survey were: amount, frequency and type of meat purchased, type of transport used for the meat shopping (e.g., on foot or by car), type of car (gasoline, diesel or GPL), distance travelled (km) in the shopping trip, beef cost as a percentage of the total shopping expenses for the day, type (refrigeration and/or freezing) and duration of storage, cooking type (stove and/or oven) and waste disposal (recycling or not). A summary of consumers' responses is reported in Table 2.

It should be noted that the survey was offered to every customer that entered the shop during several days distributed throughout the year. Those who agreed to fill out the survey were self-selected; no selection criteria (e.g. the demographic structure of the referent population) were applied.

Life cycle inventory analysis

Breeding and fattening

Emission factors associated with the production of seeds and fuel were obtained from the Ecoinvent database.[15]

Carbon dioxide (CO_2) produced as a result of electricity consumption was calculated using an emission factor of 0.385 kg CO_2 kWh^{-1}.[17] Emission factors associated with fuel consumed for cropping, animal management and transport were obtained from Ecoinvent.[15]

Emissions for the breeding and fattening stages on the farm were calculated. Emissions released from cows producing calves and from heifers to renew the herd were considered breeding activities. GHG emitted from growing and fattening animals were considered as the fattening stage.

Enteric CH_4 emissions were calculated for each category of animal (growing bulls, cows, heifers and fattening bulls) using tier 2 methodology.[16] This is based on daily gross energy intake (GEI), digestible energy (DE) and the Y_m conversion factor corresponding to the fraction of GEI converted to CH_4. Daily GEI was calculated considering LW, milk produced for calves, daily LW gain, activity (time at pasture) and cows pregnant (%).

The value of Y_m adopted was 6.5% for a higher forage diet (breeding) and 4.5% for a higher grain diet (fattening). The values of DE adopted were 65% and 70% for breeding and fattening, respectively.

Solid manure (no liquid form was produced), volatile solids (VS) and N yield yr^{-1} were calculated considering all animal categories (cows, heifers, beef) and their housing system as reported in the Italian guidelines for manure management.[18] Country-specific conversion factors of 4.8 g CH_4 kg^{-1} of VS and 0.02 kg N_2O-N kg N^{-1} were used[17] to calculate CH_4 and N_2O (nitrous oxide) from storage and manure, respectively. Methane emissions from dung deposited on pasture by cows and heifers (no grazing for beef) were calculated according to total VS excreted, livestock category and time at pasture/year. Direct nitrous oxide emission factor resulting from soil management were estimated using the IPCC default emission factor of 0.01 kg N_2O-N kg N^{-1}.[16] The method is based on nitrogen inputs, which include organic fertilizer (land-applied manure), urine and dung deposited on pasture, mineralization of soil organic matter, and crop residue decomposition (above and below-ground). The potential of soil organic carbon sequestration was not considered in the analysis.

Slaughtering, retail and consumption

Emission factors for electricity consumption and methane combustion were obtained from the National Inventory Report for Italian Greenhouse Gas and IPCC.[16,17] Emission factors associated with transport (trucks, vans and cars) were considered.[15] The emissions of refrigerant gases used in the storage systems were estimated considering different rates of gas leakage for each type of refrigeration system, then gas losses of 50, 25 and 15% of the total refrigerant capacity (kg/year) were considered for transport, slaughterhouse, and butcher's shop, respectively.[16]

The emissions related to waste disposal, packaging, detergents and captive bolts (iron) were calculated.[15,16]

Electricity consumption for meat storage at home (refrigerator and freezer) was estimated considering the volume of meat, the time stored and the factors of 0.59 kWh m^3 day^{-1} and 0.63 kWh m^3 day^{-1} for refrigerator and freezer, respectively.[19] The emissions released in cooking 1 kg of meat by gas stove or electric oven were calculated considering cooking times of 15 min and 1 h, respectively.

Allocation

Dealing with allocation of products and co-products in a multi-stage system may become an issue. There are various ways to handle data for products and co-products throughout the meat supply chain, but no single established/validated method.[20] GHG emissions were calculated within each process of the supply chain taking into account the GHG allocation between co-products. Slaughterhouse, retail, reatail-to-home transport and home consumption, is where the GHG allocation between co-products occurred. Considering slaughtered animals as the only product, no allocation was made for farm activity (breeding and fattening). Furthermore, considering only the total LW leaving the farm, no distinction was made between primary (fattening bulls or heifers) and secondary (culled cows) meat.

The main products at the slaughterhouse were beef, pork and lamb carcasses, whereas offal, blood and leather were sold as co-products. Prices provided by the plant company were 5.3, 2.9 and 7.5 €/kg for beef, pork and lamb, whereas they were 120, 6 and 12 €/100 kg for leather, offal and blood. Considering the economic values, the allocation factors were 60%, 29%, 8%, 2%, 0.5% and 0.1% for beef, pork, lamb, leather, offal and blood, respectively.

Taking into account the different prices of the meat sold, the GHG emission coming from the butcher shop were economically allocated to beef (87%), pork (8%) and lamb (5%). The GHG emissions coming from the shop-to-home transport were economically allocated taking into account the incidence of the beef (25.5%) on the total expenditure . As well for the previous stages, an economical allocation (73% to beef) was made for the GHG emissions coming from home storage and cooking.

Impact assessment

Global warming potential (GWP) was evaluated with GHG converted to equivalent units of CO_2 according to a 100-year time horizon.[21] Considering a kg of CO_2 as reference, the GWP factors per kg of CH_4, N_2O, R-134a, R-434a and R404a are 25, 298, 1,430, 3,245, and 3,922 kg, respectively. All emissions were calculated modelling data in Excel worksheets.[22]

RESULTS

Table 3 shows the processes contributing to the CF of a short supply chain for organic beef. Total CF was 24.46 kg CO_2 eq. kg^{-1} of cooked beef.

The organic farm combining breeding and fattening of native Chianina cattle emitted 20.98 kg CO_2 eq. kg^{-1} LW leaving the farm and it was the principal contributor, accounting for 86% of the total CF of the supply chain.

The emission of methane from enteric fermentation was the greatest source of GHG arising directly from farming activities (47%). Carbon dioxide emitted for energy use was the second major contributor (28%), while CH_4 and N_2O from manure management and N_2O from soil management accounted for 16% and 9%, respectively. Transport for farming operations (seeds, fuel, feed, animals) was local and accounted for less than 1% of GHG emissions within the farming stage.

Table 3. Carbon footprint expressed as kg CO_2-equivalent related to processes considered in the short organic beef supply chain.

Process	kg CO_2-eq	% GHG within supply chain
Breeding and fattening	20.98	85.8
Slaughterhouse	0.27	1.1
Butchery	1.00	4.1
Consumption	2.22	9.0
Total	24.46	100.0

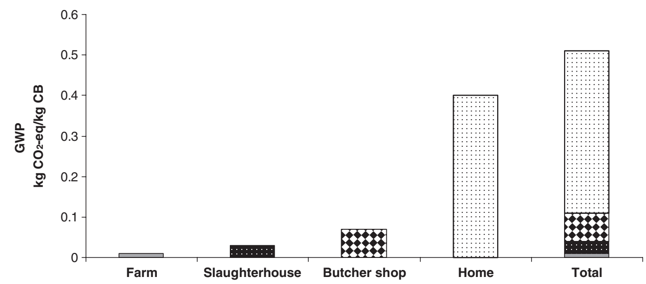

Figure 2. Carbon footprint expressed as kg CO_2-equivalent (CO_2-eq.) per kg of cooked organic beef (CB) associated with the transport carried out in a short local organic beef supply chain.

Slaughtering operations, including the transport of animals to the slaughterhouse, emitted 0.27 kg CO_2 eq. kg^{-1} of beef carcass and accounted for 1.1% of the whole supply chain. Energy use and refrigerant gas leakage were the main sources of GHG emissions within the slaughterhouse (85%). Transport of animals to the slaughterhouse accounted for 10% of GHG emitted at the plant, while CH_4 and N_2O from manure produced by animals waiting to be slaughtered accounted for about 4%. The GHG associated with the production of captive bolts and cleaners used for slaughtering operations amounted to less than 1%.

The overall GHG emitted at the butcher's shop were 1.00 kg CO_2 eq. kg^{-1} of beef sold and accounted for 4.1% on the total CF. The main contributors for this stage were refrigerant gas leaks (50%) and electricity consumption (40%). Minor contributions were associated with transport of carcasses from the slaughterhouse to the butcher's shop (7%) and packaging production (3%).

The consumption of meat including transport to the home, home storage, cooking and waste disposal resulted in 2.22 kg CO_2 eq. kg^{-1} of cooked meat, corresponding to 9% of the total CF. Energy use for storage and cooking was the main contributor to GHG emissions for this stage (81.5%). Energy consumed to cook meat (82% for a gas stove and 18% for an electric oven) was 1.41 kg CO_2 eq. kg^{-1}, while 0.4 kg CO_2 eq. kg^{-1} was for the storage of meat in a refrigerator (13%) and freezer (87%). Transport of meat from shop to home (18.1%) was the second source of emissions, while GHG emitted by packaging disposal were less than 1%.

Considering the whole life cycle investigated, the overall GHG emissions coming from the transports contributes for 2% of the total. As showed in Fig. 2, farm-to-slaughterhouse and slaughterhouse-to-butcher shop had a minor incidence compared to the shop-to-home transports.

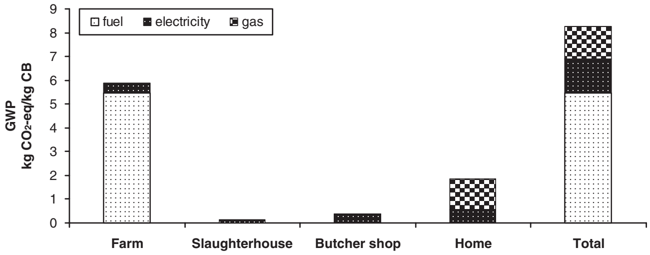

Figure 3. Carbon footprint (CF) expressed as kg CO_2-equivalent (CO_2-eq.) per kg of cooked organic beef (CB) associated with the energy consumed in a short local beef supply chain.

Figure 3 shows GHG emitted considering only the use of fossil energy as a source of emissions. The consumption of fossil energy throughout the local organic beef network emitted 8.22 kg CO_2 eq. kg^{-1} of cooked meat. Liquid fuel (diesel) used for farming activities (feed production, feeding operation and animal management) contributed 5.9 kg CO_2 eq. $kg^{-1}$and represented the main source (71%). The emissions to store and cook meat at home accounted 1.81 CO_2 eq. kg^{-1} (22% of total fossil energy consumed), and gas fuel burned for cooking operations was the main source of emissions. The GHG emitted for slaughtering and retail activities respectively accounted for 1.5% and 5% of the total GHG emitted for energy use.

DISCUSSION

Local food networks are important retail systems in Italy and the rest of the world. They are proliferating and represent a valid alternative to large retail networks. Furthermore, these food systems are important because they may guarantee the social and economic sustainability of rural communities. On the other hand, little is known about carbon pollution produced by short food supply chains and even less about local organic beef networks. Our study considered the contributions of the farm, slaughterhouse and the farm's butcher's shop and its customers. Although the local food network we considered is highly representative of beef production and consumption in Italy, we have not analysed replicates of this system and must therefore be careful not to generalize results. Nevertheless, these results may provide some interesting and useful insights into GHG emissions of local meat networks.

Breeding and fattening

Studies from specialist beef production report CF values between13 and 40 kg CO_2 eq. kg^{-1} LW.[23–25] This huge variability is mainly related to differences in the production systems analysed (i.e. organic *vs* conventional; suckler cow-calf *vs* dairy bull calf) and/or to the methodological approaches adopted (i.e. functional unit, system boundaries, emission factors and allocation methods). Therefore, direct comparisons between studies are difficult due to substantial differences in the systems evaluated and methods adopted. Our CF at the farm gate was in the range indicated above, and the proportions of GHG coming from gut and manure management agree with previously determined values.[26,9] The burden associated with feed production was lower than the 27–41% range reported in previous studies.[7,26] In those studies, the emissions associated with fuel consumption and soil management for feed production were considered together, whereas we considered these GHG sources separately. The contribution of feed production would rise to 32% of the CF at farm gate if we combined these two sources.

The 20.98 kg of CO_2 eq. kg^{-1} LW evaluated at the farm gate for an organic production system with breeding and fattening stages combined in the same farm, was higher (0.6 kg CO_2 eq. kg^{-1} LW) than that calculated for beef destined for a large retail system where production was based on breeding calves in France and transporting them approximately 1000 km to Italy for fattening.[12] Despite the longer distance travelled by animals in the Coop's study, the CF was lower than that of our system where calves were born and bred at the same farm until reaching slaughtering age. The coop study referred to Charolais and Limousin breeds raised in a convetional system (personal communication from Coop Italy). These widespread breeds are under genitic selection since long time and they have higher production efficiency than native breeds that are less selected. Charolais bulls show a higher feed efficiency, with dry matter intake lower by 0.7 kg kg^{-1} of weight gain compared with Chianina bulls.[27] In addition, organic beef cattle systems (18.2 kg CO_2 eq. kg^{-1}) have been suggested to be more carbon polluting than conventional systems (15.8 kg CO_2 eq. kg^{-1}).[8] This result was confirmed when organic and conventional beef production was considered in the Italian context. A recent Italian study showed CFs of 24.62 and 18.21 kg CO_2 eq. kg^{-1} LW for organic and conventional beef, respectively.[28] This result would seem to confirm that production efficiency has a stronger effect on total emissions rather than distance travelled by animals during breeding stages.[29]

We did not consider potential organic carbon sequestration by soil that may result from the more conservative practices of the organic system. The estimation of carbon sequestration by soil is difficult because of the high variability of soil characteristics and climate conditions, differences in soil management and the absence of certain data. However, when the carbon sink was evaluated in organic and conventional beef production systems, its contribution was limited in both.[28] The study's authors reported that the net carbon sink decreased the CF from 24.62 to 23.32 kg CO_2 eq. kg^{-1} LW in the organic system and from 18.21 to 17.71 kg CO_2 eq kg^{-1} LW in the conventional system. Carbon sequestration was two-and-a-half times higher in the organic system than the conventional one. This suggests organic practices have a high mitigation capacity that should be evaluated and confirmed over a longer observation period.

In light of the above, we may argue that the idea that local organic beef systems are more sustainable because of the shorter transport distances and conservative practices is not completely correct. Beyond the contribution of conservative practices to increasing carbon sequestration in the soil, other factors should be considered that may affect the production efficiency of the farm in order to define the sustainability of beef production.

Several practices are reported to reduce GHG emissions at farm level, and the optimum strategy should consider all processes adopted in the farm, their interactions, and the benefits achieved from mitigation measures relative to their cost. In general, we may state that mitigation of GHG at farm level may be achieved by increasing farm productivity. Breeding animals with higher weight gain per unit of feed intake, reducing the unproductive animals on the farm, and increasing production (slaughter weight reached at younger age, higher forage yield per unit of land) may contribute effectively to reducing GHG emissions per unit of meat produced. However, to maximize the sustainability of beef, strategies to improve production efficiency should be synergic with those practices aimed at increasing organic carbon sequestration by the soil.

Slaughtering, retail and consumption

The GHG emitted from slaughtering operations was less (0.27 *vs* 2.00 kg CO_2 eq. kg^{-1}) than that reported in the Coop study mentioned above.[12] The shorter distance from farm to slaughterhouse may at least partially explain this difference. The distance between our farm and the slaughterhouse was shorter (33 km) than the 350 km reported in the Coop study. For this stage, the Coop study also included intermediate transport of carcasses from abattoir to processing plant (250 km). Finally, this discrepancy might also be related to different allocation factors adopted for bovine meat and co-products (leather, offal and blood).

A Japanese study reported 0.04 kg CO_2 eq. kg^{-1} of bulls' carcasses at the slaughterhouse gate.[11] This value was calculated based on total meat yield (chicken, pork and beef) and included meat storage and packaging activities. The lower carbon emission associated with the Japanese slaughtering activities compared with our result can be related to different allocation approaches. The Japanese authors allocated emissions based on mass of products and co-products, whereas we allocated on an economic basis.

The contribution of slaughtering operations to the CF of Canadian beef production was 0.18 kg CO_2 eq. kg^{-1} of carcass.[10] The lower value may be due to the methodological and allocation procedures adopted. In contrast to our conditions, the Canadian study did not include refrigerant gas leaks, while it did consider biogas recovery from manure and waste management. In addition, even if both studies adopted an economic approach to allocate emissions between products (primary meat) and co-products (offal, blood and leather), the allocation factors were different with regard to dressing percentage, cutting yield, rendering yield and prices of primary meat and co-products.

The emissions related to butchering activities were higher than those calculated for large retail networks.[11,12] The differences are likely to depend on the higher energy efficiency of supermarkets compared with local butcher's shops.[30]

Improvements in energy efficiency may somewhat mitigate GHG production by slaughtering and retail activities. Furthermore, the use of refrigeration systems requiring lower volumes of refrigerant gas and/or a refrigerant gases with lower GWP such as ammonia, hydrocarbon or carbon dioxide would be preferred.[31] Even the adoption of appropriate operations such as regular checks of the cooling systems and avoidance of rapid changes in temperature during loading and unloading of carcasses are likely to reduce GHG emissions by food networks.[32]

The GHG emissions from home consumption were calculated based on the transport, storage, cooking and waste disposal practices declared by customers in the interviews. Our value (2.22 kg CO2 eq. kg^{-1}) is within the range 0.8–3.3 kg CO2 eq. kg^{-1} of cooked beef reported in the Coop study[12] but higher than the Japanese study's stated value for the beef cooking process of 0.34 kg CO_2 eq. kg^{-1} for which further information was not provided.[11] Energy consumed for cooking operations was the main contributor to the CF and it reflects the cooking habits of the customers interviewed. In general, cooking operations are shaped by the societal, cultural and economic characteristics of the societies in which they occur, and the development and/or implementation of more sustainable cooking practices should consider these aspects. Taking into account only the cooking devices, the evidence shows that electric stoves release less GHG than those using gas or solid fuel, with solid fuel producing the most pollution.[33]

Despite the short average distance (10 km) involved, transporting meat from shop to home represented 20% of the CF for the consumption stage or 80% of the GHG emissions from transports throughout the whole cycle. This aspect seems to contradict the idea that buying food directly from the producer is more sustainable because it avoids intermediate transport. GHG produced during shopping trips may be an important source of emissions, especially in local food networks where the short distances involved do not compensate for the small quantity of product transported per journey.[34]

When more product is transported in the same vehicle, fewer kilometres are driven per consumer or per kg of meat. Therefore, the CF burden associated with shopping trips by private car could be reduced if delivery services were offered by retailers (i.e. collective orders), especially if combined with remote ordering (e.g. through the internet). Moreover, even without alternative distribution systems, the frequency of shopping and the resulting overall distances driven may be reduced by providing better tools for planning food purchases and through increased product shelf life.[29]

Considering the discussion above as well as previously reported data,[35] the choice of local products or 'food miles' is not sufficient to guarantee environmentally sustainable food consumption; other processes and activities in the supply chain, including shopping and consumption habits, should also be carefully considered.

CONCLUSION

Local food networks are proliferating worldwide and are considered a sustainable food system even if their contribution to GHG emissions is currently not well understood.

The analysis carried out in the present study allows us to identify hot spots for greenhouse gas emissions associated with a short supply chain for organic beef. Farm activities and home consumption were the stages in the chain with the highest global warming potential. These results may help to determine the contribution of local food networks to climate change and facilitate the adoption of more sustainable practices. Their adoption would require education of farmers, retailers, consumers and policy makers, and a careful evaluation of the benefit–cost ratio.

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