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REVIEW

Greenhouse Gas Emissions from Livestock and Poultry

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ABSTRACT

In 2008 the Environmental Protection Agency (EPA) estimated that only 6.4% of U.S. greenhouse gas (GHG) emissions originated from agriculture. Of this amount, 53.5% comes from animal agriculture. Agricultural activities are the largest source of N_2O emissions in the U.S. accounting for 69% of the total N_2O emissions for 2009. In animal agriculture, the greatest contributor to methane emissions is enteric fermentation and manure management. Enteric fermentation is the most important source of methane in beef and dairy production, while most of the methane from poultry and swine production originates from manure. The main cause of agricultural nitrous oxide emissions is from the application of nitrogen fertilizers and animal manures. Application of nitrogenous fertilizers and cropping practices are estimated to cause 78% of total nitrous oxide emissions.

Based on the life cycle assessment of beef cattle, 86.15% of the GHGs are emitted during the production stage, while 68.51% of emissions take place during the production of pork and 47.82% of GHG emissions occur during the production stage of broiler chickens. The majority of the emissions from the beef cattle production comes from enteric fermentation while manure management is the major source during swine production and propane use during broiler poultry production.

Keywords: greenhouse gas, LCA, poultry emissions, beef emissions

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INTRODUCTION

The primary greenhouse gases emitted by agricultural activities are carbon dioxide (CO_2) methane (CH_4) and nitrous oxide (N_2O) (Johnson *et al.*, 2007). Livestock production contributes GHGs to the atmosphere both directly and indirectly (IPCC, 2006). The emissions can be classified based on the source of the emission; 1) Mechanical, and 2) Non-mechanical.

The majority of direct CO_2 emissions from animal agriculture are usually from fossil use, for example; the use of propane or natural gas in furnaces or incinerators and the use of diesel gas to operate farm equipment and generators results mostly in CO_2 emissions (Dunkley unpublished data), this type of emission can be described as "mechanical emissions." The use of electricity on animal production farms results in indirect emissions since the emissions do not occur on site.

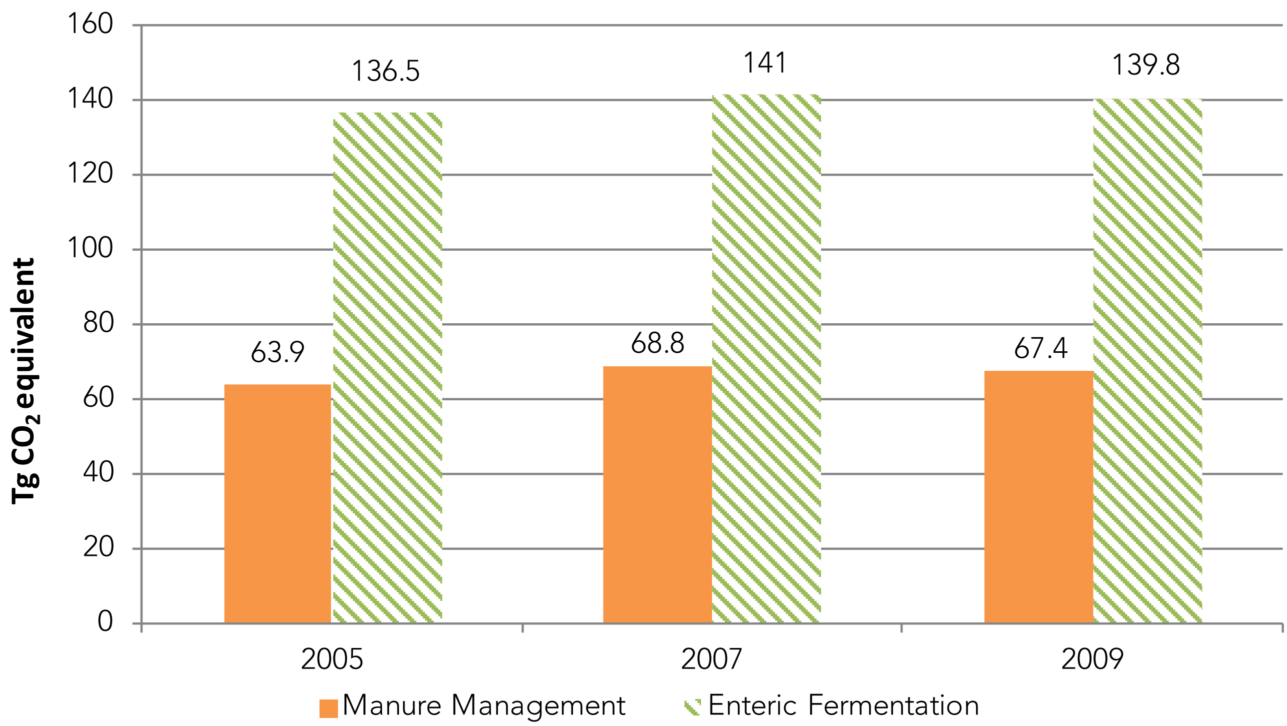
For non-mechanical emissions, direct emissions can be a by-product of digestion through enteric fermentation (CH_4 emissions). Direct emissions also occur from the decomposition and nitrification/denitrification of livestock waste (manure and urine) where CH_4 and N_2O are emitted. Managed waste that is collected and stored also emits CH_4 and N_2O. Indirect emission of N_2O occurs when nitrogen is lost from the system through volatization as NH_3 and N_x. Also, indirect emissions can result from nitrogen that is runoff or leached from manure management systems in a form other than N_2O and is later converted to N_2O offsite (IPCC, 2006). Methane from enteric fermentation and manure management are the main sources of CH_4 emissions from agricultural activities and of all domestic livestock, dairy and beef cattle are the largest emitters of CH_4. Agricultural activities are the largest source of N_2O emissions in the US accounting for 69% of the total N_2O emissions for 2009 (EPA, 2011). The majority of the N_2O emission from animal agriculture is from manure management which is the second largest (a far second to cropping practices) N_2O emitter in the agricultural sector (IPCC, 2010). Application of nitrogenous fertilizers and cropping practices are estimated to cause 78% of total nitrous oxide emissions according to Johnson *et al.*, (2007).

In 2011 the US Environmental Protection Agency (EPA) reported that the Agricultural Sector was responsible for a total of 410.6 Tera gram CO_2 equivalents (Tg CO_2e in 2005). Enteric fermentation and manure management contributed a total of 200.4 Tg CO_2e which represented about 48% of the total emissions from the agricultural Sector. During this period (Figure 1.) enteric fermentation was responsible for 136.5 Tg CO_2e and managed manure was responsible for 63.9 Tg CO_2e. In 2007, the emissions from the Agricultural sector were 425.8 Tg CO_2e a 3.7% increase. The emissions from enteric fermentation during this period were 141 Tg CO_2e a 3.3% increase over the 2005 period, while manure management emissions increased to 68.8 Tg CO_2e a 7.7% increase. The GHG emissions from agriculture showed a 1.5% reduction to 419.3 Tg CO_2e in 2009 when compared to 2007. This reduction was reflected slightly in enteric fermentation which was down by 0.8% to 139.8 Tg CO_2e and a 2% reduction in manure management emission to 49.5 Tg CO_2e (IPCC, 2010).

EMISSIONS BASED OF MANURE MANAGEMENT SYSTEMS

The type of manure management system that is used in livestock production can affect the amount of emissions and the type of gases that are emitted. A variety of livestock production systems operates in the U.S. and different manure management systems are utilized depending on the type of livestock or poultry produced (Del Grosso *et al.*, 2008). Among the manure management systems practiced in the US are; pit storage, poultry with/without litter (that is, poultry raised on a bedding material or poultry raised in cages), dry-lot, anaerobic lagoon, pasture, etc. (Table 1). Beef cattle can be raised using different manure management systems and the amount of emissions are dependent on how the manure is managed. Beef cattle raised on pasture/range exhibit relatively high N_2O emissions. In this system the manure and urine from the cattle are deposited directly on the soil reducing the likelihood of much methane

Figure 1. The distribution of livestock GHG emissions by source in 2005, 2007 and 2009



emission. When cattle are raised under conditions where the manure is collected and spread daily and there is no storage before it is spread onto the soil there is low CH_4 emissions and no N_2O emissions. Dairy cattle and swine reared in liquid/slurry manure management systems have moderate to high CH_4 emissions, while emissions from swine and dairy cattle reared in anaerobic lagoon management systems have variable CH_4 emissions as it is mostly dependent on the duration of time the manure and slurry are stored in the lagoons. In this system, the waste can be stored between 30 to 200 days; the longer the storage time, the more likely the CH_4 emissions will be high. Both the liquid/slurry and anaerobic lagoon manure systems have low N_2O emissions. Poultry reared in management systems with litter and using solid storage have relatively high N_2O emissions but low CH_4 emissions. This is because the manure is stock piled under aerobic conditions which limits the production of CH_4 (USAFGGI, 2008). Broiler, pullets, and to an extent breeders, are reared using these manure management systems. Commercial layers are typically reared in high-rise cages or scrape-out/belt systems. Here the manure is excreted onto the floor below with no bedding to absorb moisture. The ventilation system dries the manure as it is stored. In some broiler breeder houses a part of the manure is collected under the slats in the houses making it similar to the commercial layers. In this type of manure management system both CH_4 and N_2O emissions are relatively low (IPCC, 2000).

The amount of CH_4 or N_2O that is emitted from livestock also depends on environmental conditions (Del Grosso *et al.*, 2008). Methane is emitted under anaerobic conditions where oxygen is not available (Palmer and Reeve, 1993). Storage in tanks, ponds or pits, such as those used with liquid/slurry flushing systems encourages anaerobic conditions, therefore more CH_4 is produced (USAF 2008). Conversely, solid waste storage in stacks or shallow pits promotes

Table 1. Description of livestock waste deposition and storage pathways

		Relative Emissions	
Manure Management System	Description	CH_4	N_2O
Pasture/range/paddock *Ex. beef cattle*	Manure and urine from pasture and grazing animals is deposited directly onto soil.	Low	High
Daily Spread	Manure and urine are collected and spread on fields (little or no storage prior to application).	Low	Minimal
Solid storage *Ex. poultry*	Manure and urine with or without litter are collected and stored long term in bulk.	Low	High
Dry lot *Ex. Beef cattle*	Manure and urine are deposited directly on unpaved feedlots where it is allowed to dry. It is periodically removed.	Low	High
Liquid/slurry *Ex. Swine/dairy cattle*	Manure and urine are collected and transported in liquid form to tanks for storage. The liquid/slurry may be stored for long periods.	Moderate to high	Low
Anaerobic Lagoon *Ex. Swine/dairy cattle*	Manure and slurry are collected using a flush system and transported to lagoons for storage. It remains in lagoons for 30-200 days.	Variable	Low
Pit Storage *Ex. Swine/poultry layers*	Combined storage of manure and urine in pits below livestock confinements.	Moderate to high	Low
Poultry with litter *Ex. Broiler/pullet/breeders*	Enclosed poultry houses utilize bedding material (ex. Wood shavings, peanut hull, rice hulls etc.). The bedding absorbs moisture and dilutes manure. Litter is cleaned out typically once per year.	Low	High
Poultry without litter *Ex. Poultry layers/broiler breeders*	In high-rise cages or scrape-out/belt systems, manure is excreted onto the floor below with no bedding to absorb moisture. The ventilation system dries the manure as it is stored.	Low	Low

Adapted from IPCC (2000) Chapter 4.

aerobic conditions which are more favorable for N_2O emissions. High temperatures and increased storage time can also increase CH_4 emissions (Del Grosso *et al.*, 2008). Feed characteristics also play a role in CH_4 emissions. Feed, diet, and growth rate have an effect on the amount and quality of manure an animal produces (Monteny, 2006). Harper (2000) stated that there was a large effect on CH_4 emissions that is contingent on the production and use of farmyard manure. Typically, in an organic system, stock piled manure is composted, which will increase aeration limiting anaerobic production of CH_4. Higher energy feeds result in manure with more volatile solids, which increases the substrates from which CH_4 is produced (Del Grosso *et al.*, 2008). Depending on the species, this impact is somewhat offset because some higher energy feeds such as that fed to poultry are more digestible than lower quality forages fed to ruminant animals and therefore less waste is excreted. The energy content and quality of feed affects the amount of methane produced in enteric fermentation where lower quality feed and higher quantities of feed causes greater emissions (USAFGG, 2008). It was reported by the EPA (2011) that an animals feed quality and feed intake affects emission rates. In general, lower feed quality and / or higher feed intakes lead to higher emissions.The composition of the waste, the type of bacteria involved, and the conditions following excretion, all have an effect on the production of N_2O from waste management systems (EPA, 2010). In order for N_2O to be emitted, the waste must be handled aerobically where NH_3 and organic nitrogen is converted to nitrates and nitrites (Del Grosso *et al*., 2008).

EMISSIONS FROM ENTERIC FERMENTATION AND MANAGED MANURE FROM 2005 TO 2009

Ninety-one % of emissions from enteric fermentation and managed livestock manure are in the form of CH_4 (EPA, 2011). When Monteny *et al*. (2001) compared the distribution of methane emissions from enteric fermentation among animal types; poultry had the lowest amount with 0.57 lbs methane/ animal/ year when compared to dairy cattle with 185 to 271 lbs methane/ animal/ year and swine with 10.5lbs methane/ animal/ year. In 2005, livestock emissions from enteric fermentation and manure management were 200.4 Tg CO_2e (Table 2). Of this total, dairy cattle and beef cattle contributed 99.3 and 30.4 Tg CO_2e respectively from enteric fermentation. Swine contributed 1.9 Tg CO_2e from enteric fermentation while poultry contributed no emissions from enteric fermentation. For this same period, dairy cattle were responsible for 109.6 Tg CO_2e from enteric fermentation and managed livestock waste combined; beef cattle contributed 57.4 Tg CO_2e, swine contributed 22.7 Tg CO_2e, while poultry contributed 4.4 Tg CO_2e. The remaining emissions (5.66 Tg CO_2e) were from other livestock animals which were not reared in large amounts.

By 2007 (Table 3), the total amount of GHG emissions from enteric fermentation and managed livestock waste had increased by 4.69% from emission levels in 2005 to 209.8 Tg CO_2e. This was as a result of increases in enteric fermentation from dairy cattle (101.6 Tg CO_2e), beef cattle (32.4 Tg CO_2e) swine (2.1 Tg CO_2e) and horses. There were also increases in emissions from managed livestock waste in all the major livestock categories. Overall, during the two year period from 2005 to 2007, dairy cattle had a 2.5% increase in emissions (112.4 Tg CO_2e), beef cattle had the highest percentage increase of 8.7% up to 62.4 Tg CO_2e. Swine had an increase of 6.6% up to 24.3 Tg CO_2e, while poultry had a 4.5% increase (4.6 Tg CO_2e) during the 2005 to 2007 period (EPA, 2011).

In 2009 (Table 4), a reduction in emissions of 1.28% from the 2007 levels was observed even though these emissions were not as low as in 2005. The emissions from enteric fermentation from the major livestock categories showed a reduction in enteric fermentation from dairy cattle (99.6 Tg CO_2e), while beef cattle showed an increase (33.2 Tg CO_2e). Enteric fermentation emissions from swine remained the same as in 2007. For the major livestock categories overall reductions in emissions from enteric fermentation and managed livestock waste combined were observed in all with the exception of beef cattle. Dairy cattle had a 2% reduction down to 110.1 Tg CO_2e from the 2007 levels of 112.4 Tg CO_2e. Beef cattle had a 1.7% increase up to 63.5 Tg CO_2e, swine had a reduction of 4.9% (23.1 Tg CO_2e) while poultry had a 6.5% reduction in the emissions from 2007. Of all the major livestock categories (dairy, beef cattle, swine and poultry) only poultry had an overall reduction (2.2%) in emissions from 2005 to 2009 (EPA, 2011). The emission estimates reported here were adapted from the EPA's 2011 report. Several modifications to the estimates relative to the previous estimates had an effect on the emission estimates. The modifications included; the average weight assumed for mature dairy cows from 1550 pounds used in previous inventories to 1500 pounds. There were also slight modifications from the 2008 numbers in the populations of calves, beef replacement and feedlot cattle. Swine populations were also modified so that the categories "<60 pounds" and "60- 119pounds" changed to "<50 pounds" and "50-119 pounds".

Table 2. Greenhouse gas emissions by livestock category and source in 2005

	Enteric Fermentation	Managed Livestock Waste		Total
	CH_4	CH_4	N_2O	
Animal Type	Tg CO_2 equivalent			
Dairy Cattle	99.3	2.8	7.5	109.6
Beef Cattle	30.4	21.4	5.6	57.4
Swine	1.9	19.0	1.8	22.7
Horses	3.5	0.06	0.3	3.86
Poultry	0.00	2.7	1.7	4.4
Sheep	1.0	0.1	0.4	1.5
Goats	0.30	0.00	0.0	0.3
Total	136.5	46.6	17.3	200.4

Table 3. Greenhouse gas emissions by livestock category and source in 2007

	Enteric Fermentation	Managed Livestock Waste		Total
	CH_4	CH_4	N_2O	
Animal Type	Tg CO_2 equivalent			
Dairy Cattle	101.6	2.9	7.9	112.4
Beef Cattle	32.4	24.2	5.8	62.4
Swine	2.1	20.3	1.9	24.3
Horses	3.6	0.6	0.6	4.8
Poultry	0.00	2.8	1.8	4.6
Sheep	1.0	0.1	0.1	1.2
Goats	0.3	0.0	0.0	0.3
Total	141.0	50.7	18.1	209.8

Table 4. Greenhouse gas emissions by livestock category and source in 2009

	Enteric Fermentation	Managed Livestock Waste		Total
	CH_4	CH_4	N_2O	
Animal Type		Tg CO_2 equivalent		
Dairy Cattle	99.6	2.7	7.8	110.1
Beef Cattle	33.2	24.5	5.8	63.5
Swine	2.1	19.0	2.0	23.1
Horses	3.6	0.5	0.3	4.4
Poultry	0.0	2.7	1.6	4.3
Sheep	1.0	0.1	0.3	1.4
Goats	0.3	0.0	0.0	0.3
Total	139.8	49.5	17.9	207.2

These changes attributed to an average reduction in emissions from dairy cattle of 11.5 Gg or 0.8% per year and beef cattle emissions decreased an average of 0.13 Gg or less that 0.01% per year over the entire time series relative to the previous inventory (EPA, 2011).

Of course, in order to discuss emissions from enteric fermentation one must consider the size (weight) of the livestock and the number of each type of livestock grown each year. Larger animals will produce more methane than smaller animals and the amount of methane emitted is increased with increasing number of animals grown (Del Grosso *et al.*, 2011). The type of digestive system will also determine the amount of methane produced. Cattle are ruminant animals with a four compartment stomach. Their digestive tract is designed for microbial fermentation of fibrous, high cellulose materials. One of the by-products of microbial fermentation is methane (Stevens and Hume, 1998). Poultry and swine are mono-gastric animals with a simple stomach and little microbial fermentation taking place; therefore they have less enteric methane production (Frédéric *et al.*, 2007). The feed quality also plays a role in the amount of CH_4 that is emitted, poorer quality high-fiber diets will likely result in greater CH_4 emissions than higher quality diets that contains more protein (Del Grosso *et al.*, 2011). Typically, CH_4 is usually produced following the degradation of carbon components during digestion of feed and manure (Monteny *et al.*, 2006). Husted (1994) stated that the rumen was the most important site of methane production in ruminants (breath), while in monogastric animals such as swine and poultry, methane is usually produced in the large intestines. The manner in which animal manure are stored whether indoors in sub-floor pits or outdoors are also relevant sources of CH_4 production (Husted, 1994). Enteric fermentation is the most important source of methane in the dairy industry, while, the majority of CH_4 emissions from the pig and poultry industries originates from manures (Monteny *et al.*, 2006). There is also a range in the total emissions in dairy cows that is caused by differences in diet and housing systems. For example; there are lower emission rates for tying stalls and higher rates for cubicle houses (Groot Koerkamp and Uenk, 1997).

FARM-GATE AND LIFE CYCLE ASSESSMENT EMISSIONS

Greenhouse gas emission from the different livestock categories can also be evaluated based on "Life Cycle Assessment" (LCA). This involves not only the farm-gate emissions but also an inventory of the material and energy inputs and the emissions associated with each stage of production. The LCA looks at the "cradle to grave" energy use (Guinee *et al.*, 2001). This assessment could include; fertilizer production and transportation, crop production and transportation, feed additive manufacturing and transportation, animal production facilities, transportation to processing plants, processing, distribution to retail markets, consumer use of the product and disposal of packaging (Guinee *et al.*, 2001). This can be a very complex process and researchers have used different boundaries when approaching the LCA for different livestock. The Environmental Working Group (2011) examined GHG emissions from beef cattle and poultry, based on "farm-gate" emissions and showed that each of the livestock category assessed displayed differences in various areas of production (Figure 2). Farm-gate emissions here are based on the emissions that occur within the bounds of the farm plus the feed production and did not include processing of the meat. The EWG reported that the majority (7.51 kg CO_2e) of GHGs was emitted to produce 1 kg beef at the farm-gate was as a result of enteric fermentation. In poultry production the majority (1.26 kg CO_2e) of GHGs emissions was from feed production and no GHGs emissions from enteric fermentation. To produce 1 kg of edible beef at the farm-gate resulted in the emissions of 1.75 kg CO_2e of N_2O from manure, while 0.28 kg CO_2e N_2O was emitted from manure to produce 1 kg edible chicken meat. Emissions of GHGs from energy use at the farm-gate can also be compared for different livestock categories. On-farm energy use to produce 1 kg of beef at the farm-gate resulted in the emission of 0.23 kg CO_2e, while to produce 1 kg chicken meat at the farm-gate resulted in the emission of 0.26 kg CO_2e GHGs. It was also reported that 4.8 kg CO_2e was generated to produce 1 kg of edible eggs. The majority of the emissions from the production of edible eggs occurs at the farmgate (Figure 3) and as with chicken meat production, these emissions came from feed production, on-farm energy use, N_2O from poultry litter and fuel combustion (EWG, 2011). The Environmental Working Group (2011) also reported LCAs from dairy production, reporting yogurt, cheese and 2% milk LCAs. The production of whole milk at the farm-gate resulted in 1.02 CO_2e per Kg of edible whole milk, while only 0.67 kg CO_2e was emitted per kg of edible 2% milk. Domestic cheese production at the farm-gate resulted in the emission of 9.09 kg per kg of edible cheese (Figure 3). For yogurt production, the majority of emissions occurred post-farm gate (1.03 kg CO_2e per kg yogurt). Methane emissions from enteric fermentation were the primary source of pre-farm-gate GHGs for cheese, milk and yogurt production (EWG, 2011).

A number of different GHG emission values from LCA have been published for different livestock categories (Table 4). Based on these publications the emissions from beef production at the farm-gate ranged from 14.8 to 20 kg CO_2e/kg of product at the farm-gate with an average of 16.25 kg CO_2e/kg of product at the farm-gate. The figures for swine ranged from 3.4 to 6.4 kg CO_2e/kg of product at the farm-gate with an average of 4.82 kg CO_2e/kg of product at the farm-gate, while the emissions for poultry ranged from 2.33 to 4.6 kg CO_2e/kg of product at the farm-gate with an average of 3.09 kg CO_2e/kg of product at the farm-gate. According to reports by EWG (2011), beef cattle LCA emissions in kg CO_2e/kg of consumed food was 27 kg. They also reported that the LCA for pork was 12.1 kg CO_2e/kg of consumed food, while chicken had an LCA of 6.9 kg CO_2e/kg of consumed food (Figure 3).

The LCA emissions that were calculated by the EWG included the production emissions. This included the emissions before the product left the farm plus all avoidable and unavoidable waste. Calculations were also done to include post-production emissions which included processing, transport, retail, cooking and waste disposal (EWG, 2011). Of the 27 kg CO_2e emitted to produce 1 kg of beef (consumed) only 3.73 kg CO_2e was post farm-gate emis-

Figure 2. Sources of beef and poultry production emissions

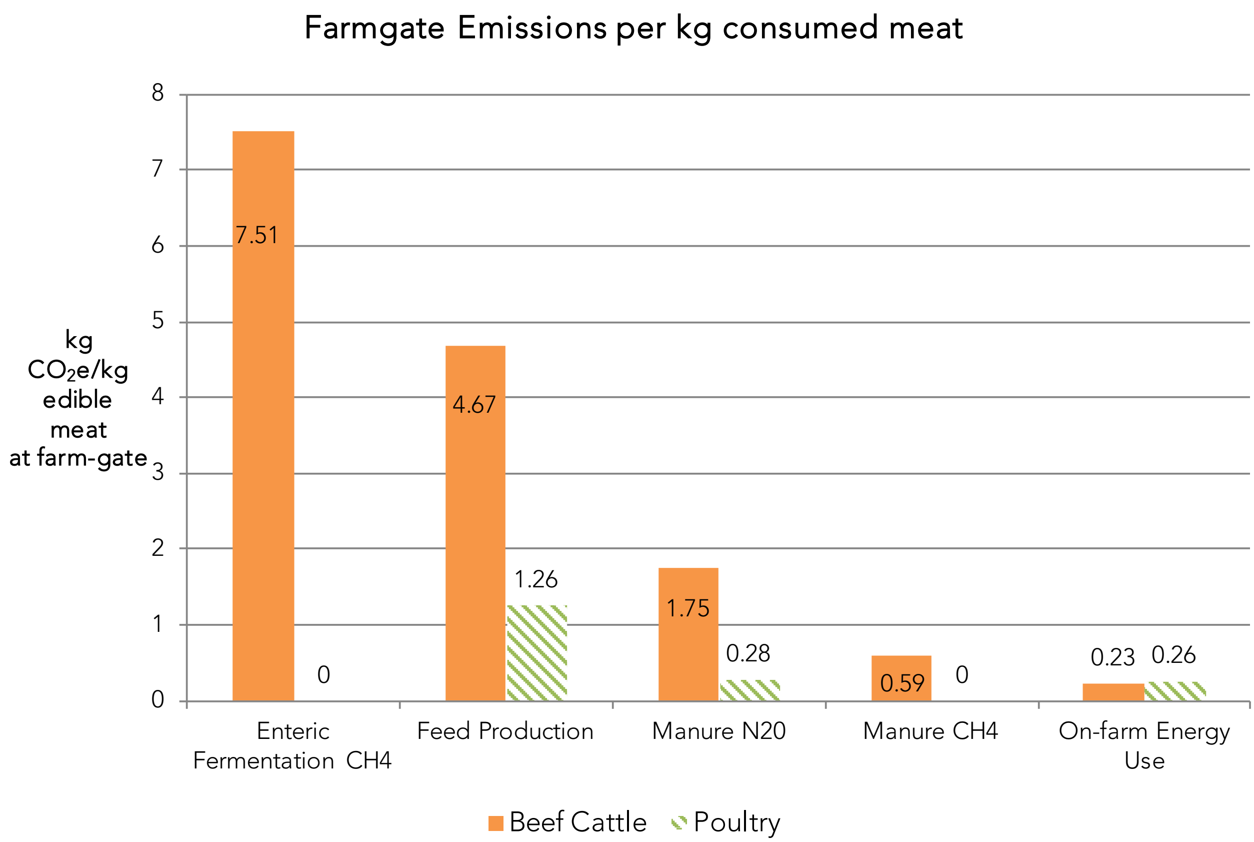


Figure 3. LCA production and post-production emissions of beef and dairy cattle, swine and poultry

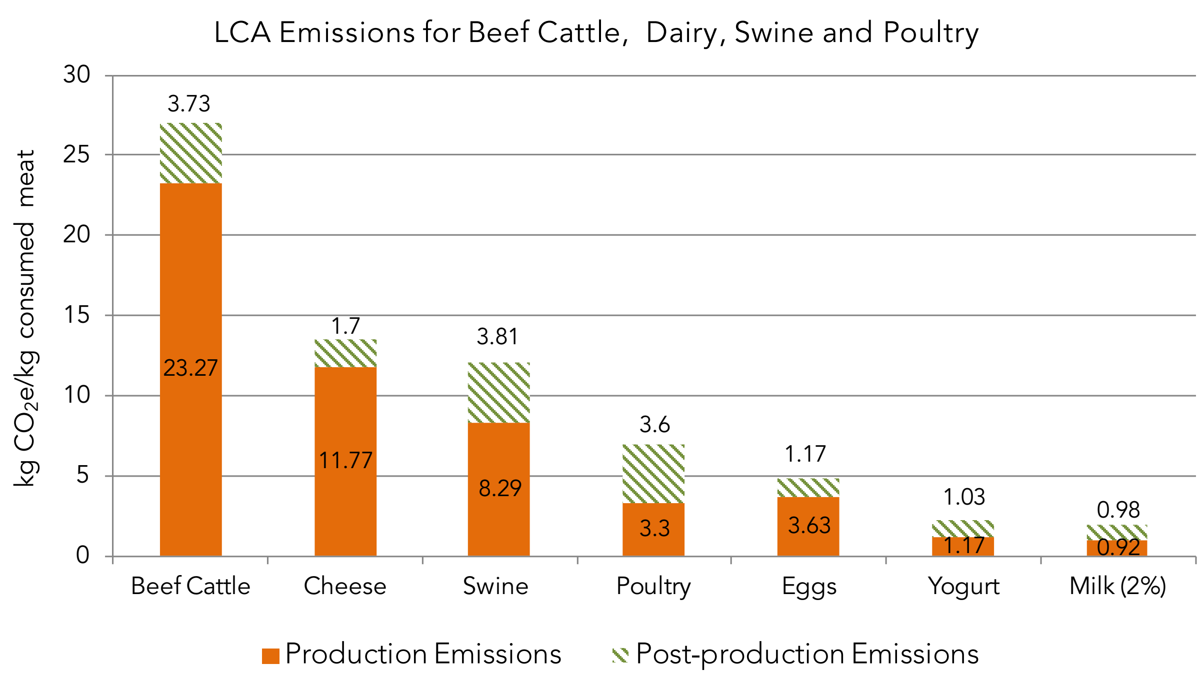
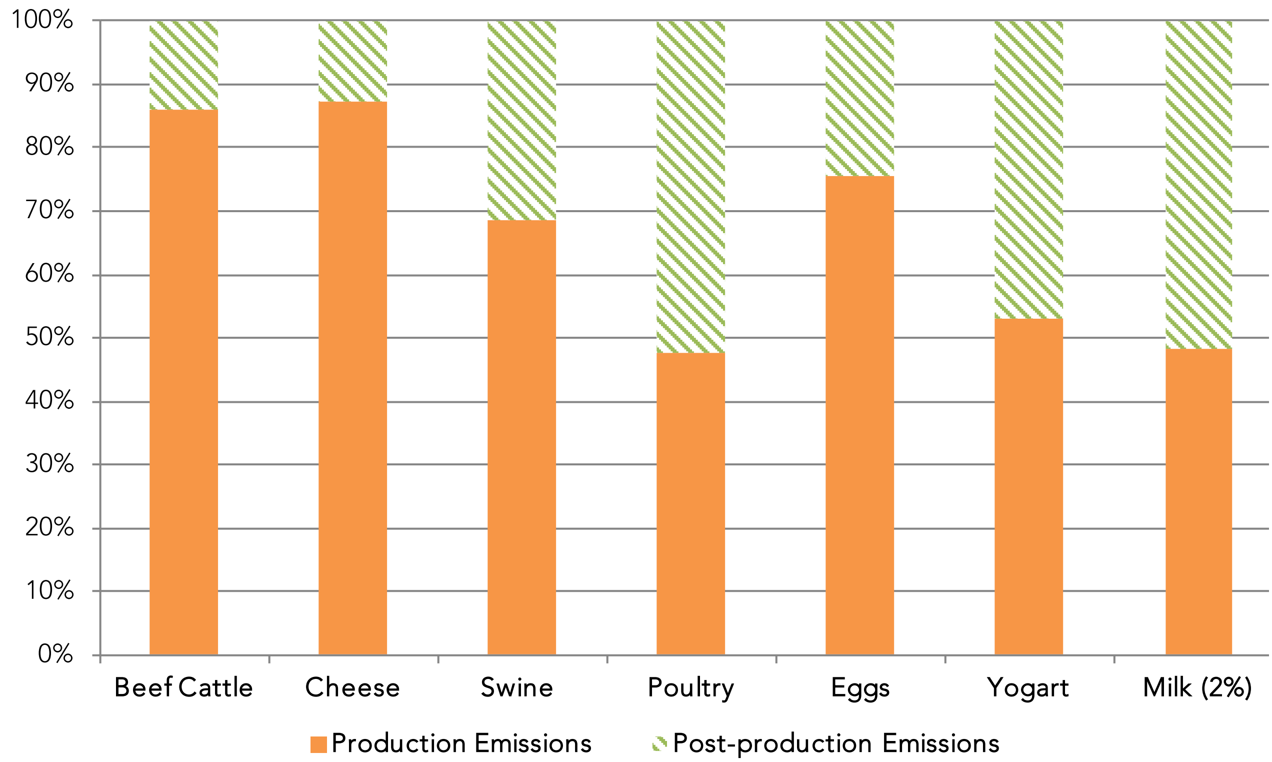


Figure 4. Percent production and post-production emissions for beef and dairy cattle, swine and poultry LCA



sions (Figure 3). A total of 3.81 kg CO_2e was emitted post farm-gate to produce 1 kg of consumed pork, while 3.3 kg CO_2e from the total 6.9 kg emitted to produce 1 kg chicken (consumed) was post farm-gate.

From the LCA emissions it is clear that the majority (86%) of the emissions from beef cattle production occur during the production stage while only 14% of the LCA emissions occur post-production (Figure 4). This is similar to swine where the majority (69%) of emissions was also observed during the production stage. A different scenario was observed for the poultry LCA where 48% of the emissions were observed during the production stage.

CONCLUSIONS

Of the major livestock animals reared, emissions from poultry production systems generate the lowest levels of emissions to produce one kg CO_2e/kg meat at farm-gate while dairy cattle produce the lowest levels of emissions to produce one kg CO_2e/kg product at farm-gate. Dairy cattle emit the highest levels of GHG per animal followed by beef cattle and swine. The majority of the emissions from beef production come from enteric fermentation and feed production with the cow to calf and the steer calf stages generating more than 65% of the total GHG emissions from this livestock category. In all the stages of beef production, high levels of CH_4 from enteric fermentation are generated. For dairy cattle, the majority of emissions are from enteric fermentation, similar to beef cattle production. Methane emission from manure storage and feed production

Table 5. Greenhouse gas emissions by livestock category and source in 2007

Livestock Category	Average GHG emissions kg CO_2e/kg Product at farm-gate from all references	GHG Emissions kg CO_2e/kg of product at farm-gate	Peer reviewed, independent, Government Sources
Beef	16.25	15.9	DERFA, 2008
		20	Phetteplace et al. 2001(US)
		14.8	Pelletier et al., 2010
		15.32	Subak, 1999
		15.23	EWG, 2011
Swine	4.82	6.4	DERFA, 2008
		3.4-4.2	Pelletier, 2010
		5.5	Wiltshire, 2006
		4.62	EWG, 2011
Poultry	3.09	4.6	DERFA, 2008
		2.36	Pelletier, 2008
		3.1	Wiltshire, 2006
		2.33	EWG, 2011

in dairy cattle production also contributes to high levels of GHGs. Swine production emits GHGs primarily from manure management and fuel combustion. Only a small amount of CH_4 is emitted during digestion when compared to ruminants. At least one third of GHG emitted from swine production is from post farm-gate activities. The largest contributor to GHG emissions from poultry production is feed production. The highest emissions from poultry on-farm activities are from fuel combustion from energy use and manure management. In broiler production post farm-gate emission makes up more than half of all the emission, while post farm-gate emissions from egg farm operations accounts for less than one quarter of the total emissions.

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