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Greenhouse Gas Emission from the Danish Broiler Production estimated via LCA Methodology

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Content

Abstract

Aim & focus

The aim of this study was to quantify the global warming potential (GWP) of chicken meat produced at Danish farms. Furthermore, the aim was to identify the hot spots of the products/processes that contribute substantially to the GWP of chicken. The functional unit was 1 kg of chicken defined as carcass weight for human consumption, i.e. meat, bones, liver, heart, kidneys, feet and neck were included while feathers, head, blood and intestines were excluded. The study includes GWP from the following rearing units, the hatch egg production, the hatchery, the broiler production, the slaughterhouse and all internal and external transports. No further GWP after the slaughterhouse was included in this study.

Methods

The GWP estimates in this study were based on a consequential approach using system expansion. The main by-products were manure and slaughter waste (feathers, head, blood and intestines) and, therefore, the system was expanded to include the avoided production of artificial fertilizer (ammonium nitrate) and mink feed (fish meal and maize), respectively.

The GWP was calculated according to the Intergovernmental Panel on Climate Change (IPCC) 2007, using a 100 year time span (IPCC, 2007). Capital goods (e.g. buildings, machinery, roads, maintenance etc.) are only included in the basic data taken from existing data sources such as Ecoinvent (Ecoinvent, 2007). Production infrastructure at the farms and slaughterhouses such as buildings, machinery etc. was not included.

Results

The average live weight of a chicken was 2.127 g and the corresponding carcass weight was 1.489 plus 181 g of by-products (heart, liver, feet, neck), which is also used for human consumption.

The GWP of one broiler packed at the slaughterhouse and ready for shipment was estimated to 3.85 kg CO_2 eq. per broiler corresponding to 2.31 kg CO_2 eq. per kg carcass weight due to the carcass weight of 1.670 kg.

The contributor to the GWP of chicken meat was: hatch egg production, incl. rearing unit and hatchery (13.5%), broiler production (76.4%) and slaughtering (10.1%). At broiler farm level the major contributor to GWP was feed (91%).

The variation between broiler farms was quite large ranging from 2.31 to 3.30 kg CO_2 eq. per produced broiler.

Conclusions

The large variation in feed efficiency observed between Danish broiler producers despite virtually same level of feed quality available across houses and farms emphasize that the largest potential for reducing GWP here and now is to focus on intensified management and daily working routines in order to improve both weight gain and feed efficiency at the individual broiler producer in order to reduce GWP input in broiler production. The GWP of Danish chicken meat is within the same level as found in other LCA studies.

Background of LCA

A Life Cycle Assessment (LCA) is the assessment of environmental effects that a product or a service has during its lifetime, in principle from cradle to grave. In some cases, however, only a part of the life cycle is included in the assessment. System boundaries are included because the destiny of a given product is not always known when the product is sold, or the product is used as a part of other products.

A strength of the LCA approach is that processes in the creation of a product/ service, that have the highest environmental impacts, can be identified. Thereby, the LCA may help the producers to make decisions concerning where to take actions in order to reduce the environmental impact, for example by optimising energy consuming processes.

A LCA can contain a number of environmental impact categories, e.g. global warming, acidification, eutrophication, land use and photochemical smog. The different impact categories can be normalized to a single score, either monetary units or Quality Adjusted Life Years (QALYs). In this report only the global warming potential (GWP) is covered and no single score calculation is therefore necessary.

Goal and scope

Focus

The current analysis and report follows the ISO 14044 guidelines (ISO, 2006). The aims of this study were thus to (1) quantify the global warming potential (GWP) of Danish broilers and (2) to identify products/processes with a major contribution to GWP of Danish broilers.

The focus of the report was to identify sources of global warming potential of Danish broilers; other environmental impacts were not covered in this report.

The results of this study were for use within a project called “Climate friendly poultry production”. The partners in the project include representatives from the hatch egg industry, a feedstuff company, a ventilation company, the broiler producers and two slaughter companies. The purpose of the project was to gain knowledge about the GWP of Danish broiler production. The results were not to be used as a comparative assertion (ISO, 2006).

This report has been critically reviewed by an external LCA-expert (see appendix).

Functional Unit

The functional unit in this report was 1 kg of chicken meat defined as carcass weight, i.e. bones, liver and heart were included but feathers, head, blood and intestines were not included. The broilers were foiled and packed and thereby ready for transport to supermarkets, i.e. no further GWP after the slaughterhouse was included in this study. The inventory was related to a whole broiler but a given resource/input could be converted to the functional unit by dividing with 1.670 kg which is the average carcass weight of a broiler.

Data

Data from two rearing units, two hatch egg producers, one hatchery, six broiler producers and two poultry slaughterhouses were supplied by Knowledge Centre for Agriculture, Poultry (Bahrndorff and Jørgensen, pers. com.). These data were collected for the production year 2009. Otherwise data were used from different sources such as the Ecoinvent database, literature sources and personal communications with key persons.

Methods

TOOLS

The calculations were made using the PC tool SimaPro 7.1 (PRé Consultants, 2008) together with LCA databases (Ecoinvent and LCA Food DK) that contain data for specific processes.

LCIA

The chosen life cycle impact assessment method (LCIA) is a single issue method called: “IPCC 2007 GWP 100A”. It only takes the global warming potential into account and is calculated according to IPCC 2007, using a 100 year time span. Using IPCC 2007, 1 g N_2O and 1 g CH_4 correspond to 298 and 25 g CO_2, respectively. As a default the Ecoinvent database includes biogenic CO_2 (carbon incorporated into plants/trees from the atmosphere). However, because the process of human consumption of chicken meat is not included, the LCA reported here excluded biogenic CO_2 sources. Furthermore, GWP that arises due to land transformation was not included in this study due to lack of common methodology. This means that e.g. GWP arising from transformation of forest to fields for soybean production was not included and, therefore, GWP for soybean meal is underestimated (Dalgaard et al., 2008; Olesen, pers. com.).

Capital goods (e.g. machinery, roads, maintenance etc.) were included in the basic data in the Ecoinvent database (Ecoinvent, 2007). However, buildings at the production facilities (farmhouses, slaughterhouses, etc.) were not included, because they were expected to be of minor importance.

APPROACH

The LCA reported here was based on a consequential approach (CLCA). In many processes more than one product was produced (joint production). In such cases it was necessary to divide the environmental impact from the process between the products (the main product and by-products). This was done by *system expansion*, where the impacts of the by-products were included in the assessment, rather than splitting the impacts due to e.g. weight or value of the different products (Kørnøv *et al.,* 2007; Thomassen *et al.,* 2008). CLCA implied marginal data for a given product and a marginal supplier was characterised as being able to increase its production at an economic favourable price. Thus CLCA had two important features: 1) it tried to model the processes that were influenced by a change in demand, 2) allocation of by-products was avoided by system expansion.

Although the LCA reported here was based on CLCA, a few standard processes from Ecoinvent were based on an allocation approach, such as palm oil. However, the significance of this process was limited, i.e. <1.5 % of the total GWP/broiler.

SYSTEM DESCRIPTION

This investigation included greenhouse gases emitted from the rearing unit (of future hens for hatch egg production), the hatch egg production, the hatchery, the broiler production and the process of slaughtering together with all internal and external transports. For more details, see section on *"process description"*.

SYSTEM BOUNDARIES

In this analysis the lower boundary of the analysis was the rearing unit where hens grow up and eventually were used in the hatch egg production. The GWP associated with production of feed pellets by the feed stuff companies was expected to be of minor importance and was therefore not included. One broiler consumes 3.1 kg feed pellets from feed companies according to the data from the six broiler producers in this study. The "grandparent-generation" which typically was located in Sweden was not included in this study due to its insignificance on GWP. Thus, in order to produce one broiler, only 0.00006 chickens in the grandparent generation was needed. The upper boundary was the foiled and packed chicken meat at the slaughterhouse ready for transport to the supermarket. Due to the production of by-products, the system was expanded to include the avoided production of artificial fertilizers; mink feed and district heat/barley due to the broilers production of manure, slaughter waste and dead/discarded chickens, respectively.

In all six broiler farms, some or all wheat was home-grown. However, the focus in the project was to identify what could be done in the chicken production itself with respect to GWP and, therefore, the home-grown plant production was not included, i.e. a common GWP table value was used for wheat that was either bought from the feed stuff company or home-grown.

Process description

An overview of the flow diagram of broiler production is given in figure 1. The following inputs were used in the broiler production: day-old chickens, feed, water, straw for heat generation, electricity, oil, gas, diesel fuel, bedding material and detergents for cleaning. The by-products from the broiler production *per se* were manure and dead chickens. The hatch egg production requires mainly the same type of inputs and generates the same type of outputs as the broiler farms. The slaughterhouse uses electricity, gas, district heat, water, packaging materials and detergents for cleaning and produces by-products in the form of slaughter waste (feathers, head, blood and intestines) which are processed and used as mink feed. It should be noted that the feet, neck, heart and liver is used for human feed and is therefore included in the carcass weight. Due to the production of by-products, the system was expanded to include production of artificial fertilizers, mink feed and district heat/barley (DAKA) due to the broilers production of manure, slaughter waste and dead/discarded chickens, respectively (see *Inventory* section).

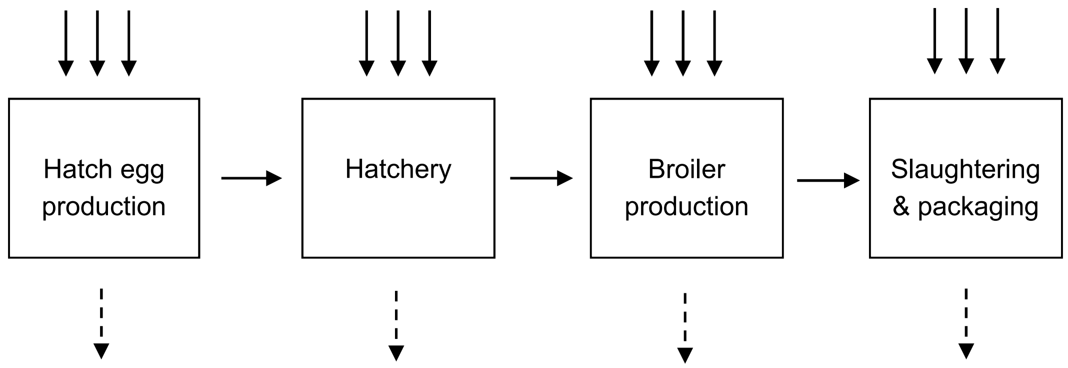

Figure 1. Main flow diagram in broiler production. Boxes illustrate processes, arrows illustrate inputs from outside (undefined) and transport from one process to another. From each process there are by-products indicated by dashed arrows. The quantitatively major by-products are manure and slaughter waste which are used as fertilizer and mink feed, respectively. The quantitatively minor by-products are dead/discarded broilers and egg shells which are processed at DAKA. The hatch egg production also includes the rearing unit of the parent generation.

Production of broiler chickens is carried out in a relatively similar way in Denmark. The birds were delivered to the production farm as day-old chickens from the hatchery and after approximately 5-6 weeks they reached a live weight of 2.2 kg and a carcass weight of 1.5 kg. The broiler producers used concentrates with relatively high protein content and different amino acid supplements to achieve a high average daily gain. The concentrates were mixed with own wheat at the farm. The hatchery was supplied with eggs from the hatch egg producers and the hens here were designated the parent generation. The hatch egg producers also had a rearing unit where the parent generation was housed from they arrive as day-old chickens from abroad (mainly Sweden) and until they were 18 weeks of age.

Life cycle inventory

All data presented in the following are from 2009 and were supplied by Knowledge Centre for Agriculture, Poultry (Bahrndorff and Jørgensen, pers. com.). The inventory was based on two rearing units (of future hens for hatch egg production), two hatch egg producers, one hatchery, six broiler producers and two poultry slaughterhouses. In the following the usage of inputs such as feedstuffs, electricity, transport etc. are given per broiler and not per kg meat. Data from the two slaughter companies showed the same average live weight, namely 2.127 g and the corresponding carcass weight was 1.489 plus 181 g of by-products (heart, liver, feet, and neck) which was also used for human consumption. I.e. a given input could be converted to the functional unit (= 1 kg chicken meat) by dividing with 1.670 kg. Note that this average live weight was lower than what has been obtained by the six broiler producers (see table 3). The consequence of using 1.670 kg meat compared to 1.755 kg, which was the carcass weight including by-products from the six broiler producers (2.236 kg*0.785), was a higher GWP per kg chicken meat. The actual GWP for the six broiler producers using 1.755 kg meat is presented in the section: *"alternative model scenarios".*

In the following tables 1, 2, 3 and 4, the inventory is described for the hatch egg production, the broiler production and the slaughterhouses.

Rearing unit, the hatch egg production and hatchery

Table 1 presents the inventory for the production of one day old chick. The inventory is split up according to the inputs used in the rearing unit, the hatch egg production and the hatchery. The variation between the two hatch egg producers was almost non-existing and the data presented in table 1 is therefore an average of those two hatch egg producers.

Table 1. Inventory for production of 1 day old chick based on data collection from 2 Danish rearing units, 2 Danish hatch egg producers and 1 hatchery. The unit is "g per day old chick" unless otherwise stated.

	Rearing unit	Hatch egg producer	Hatchery
Transport feed (kgkm/chick)[1]	1.7	8.8	
Wheat	31	195	
Soybean meal[2]	10	45	
Oat	9	9	
Maize	1	8	
Palm oil[3]	1	6	
Supplements[4]	4	30	
Electricity (kWh/chick)	0.0058	0.0268	0.0812
Oil (L/chick)	0.0030	0.0024	0.0034
Cleaning agents[5]	≈0	≈0	≈0
By-product for soup[6]		23	
By-product for egg powder[7]		3	
Waste for DAKA[8]	≈0	2	17

[1] includes transport of feed from feed company to producer (56g*30km & 293g*30km)

[2] small amounts of fish meal and sunflower meal was converted to soybean meal – see text

[3] palm oil was assumed to be the marginal oil – see text

[4] supplements include minerals, vitamins and amino acids

[5] include different agents used for cleaning and disinfection but due to the insignificant amounts GWP was set to zero

[6] when the egg laying parent birds are slaughtered they are used in various soup products for human consumption. Due to the small amount of by-product and lack of data for the soup production, the GWP for this by-product was assumed to be zero

[7] include discarded eggs from the hatch egg production which are processed to egg powder and used for human consumption. Due to the small amount of by-product and lack of data for the egg powder production, the GWP for this by-product was assumed to be zero

[8] include dead birds in the production and egg shells

Broiler production

Table 2 presents the inventory for the production of one broiler based on data collected from six Danish broiler producers. The variation is illustrated by minimum and maximum values. The average values on feed usage are representative for Danish broiler production in general since the values are in accordance with other investigations on feed usage in broiler production (Jørgensen, pers. com.). From the minimum and maximum values it is seen that different sources of energy is used to heat up the broiler houses, where either oil, gas, straw or a combination is used.

Table 2. Inventory for production of 1 broiler based on data collection from 6 Danish broiler producers.

	Average	Minimum	Maximum
Transport (kgkm/day old chick)[2]	5.7		
Transport feed (kgkm/broiler)[3]	310	263	367
Wheat (g/broiler)	2,450	2,055	2,704
Soybean meal (g/broiler)[4]	894	693	1,169
Maize (g/broiler)	91	13	166
Rapeseed (g/broiler)	209	142	281
Palm oil (g/broiler)[5]	79	67	99
Supplements (g/broiler)[6]	117	94	156
Electricity (kWh/broiler)	0.215	0.113	0.379
Oil (L/broiler)	0.020	0	0.10
Diesel (L/broiler)	0.0029	0.0002	0.0066
Gas (MJ/broiler)	0.016	0	3.63
Straw (kg/broiler)[7]	1.06	0	3.42
Water (L/broiler)	7.0	6.2	8.6
Hatch eggs (no/broiler)	1.06	1.04	1.10
Cleaning agents (g/broiler)	0.67	0.37	1.26
Waste for DAKA (g/broiler)	23	13	31

[1] includes feed for dead and discarded broilers

[2] includes transport of day old chick from hatchery to producer (38g*150km)

[3] transport of feed from feed company to producer (3.10kg*100km). Note that in average 0.74 kg of wheat was home-grown and therefore not included for transport

[4] small amounts of fish meal was converted to soybean meal – see text

[5] palm oil was assumed to be the marginal oil – see text

[6] includes supplements of minerals, vitamins and amino acids

[7] mostly burned for heating purposes and a small amount is used as bedding material

The variation in production results between the six broiler farms is shown in table 3. A relatively large variation is seen but the average and variation is consistent with other investigations on feed usage for broilers (Jørgensen, pers. com.).

Table 3. Variation in production results between the 6 broiler producers.

	Average	Minimum	Maximum
Feed (kg/broiler)	3.84	3.21	4.40
Live weight (g/broiler)	2,236	2,065	2,375
Efficiency (kg feed/kg broiler)[1]	1.72	1.48	2.13

[1] “kg broiler” is corresponding to kg “live weight”

Slaughterhouses

The energy supply for the two slaughterhouses is quite different (see table 4). In one slaughterhouse they use gas, district heat and electricity while the second slaughterhouse produces electricity from gas burned in a gas motor, which is sold to the grid and at the same time buy electricity from the grid. The heat from the gas motor is sold as district heat in a nearby town.

Table 4. Inventory for slaughterhouse A and B.

	A	B
Transport broiler (kgkm/broiler)[1]	362	321
Electricity bought (kWh/broiler)	1.06	0.594
Electricity sold (kWh/broiler)		0.403
Gas (MJ/broiler)	0.444	3.931
District heat bought (kWh/broiler)	0.183	
District heat sold (kWh/broiler)		0.133
Cardboard (g/broiler)	54	6.4
Plastic (g/broiler)	14	3.8
Foil (g/broiler)	15	0.3
O_2 (ml/broiler)[2]	1.5	1.5
CO_2 (g/broiler)[2]	16	16
Cleaning agents (g/broiler)[2]	6.4	6.4
COD (mg/broiler)[3]	3.2	0.013
"By-products" (g/broiler)[4]	181	181
Slaughter waste (g/broiler)[5]	457	457

[1] average of all broiler producers to each slaughterhouse (A: 2.127 kg*170 km; B: 2.127 kg*151 km)

[2] based mainly on information from one of the two slaughterhouses and therefore no difference between slaughterhouses

[3] COD = chemical oxygen demand for waste water

[4] These "by-products" include heart, liver, feet and neck which are used for human consumption

[5] Slaughter waste included feathers, head, blood and intestines which was processed to mink feed (see table 8)

Feed

The consequential approach is to model all feed components as soybean meal and barley with respect to the content of protein and energy in the feed ration (Dalgaard et al., 2007; Nguyen et al., 2011). Another consequential approach, used in this report, is to consider all feed components as marginal (see meaning of "marginal" under *Methods*) unless they are originating from a constrained production. This is the case for soybean oil which is not produced by the demand for soybean oil but only for the demand of soybean meal (Schmidt and Weidema, 2007). Thus, the marginal oil was assumed to be palm oil (Dalgaard et al., 2008). A small amount of fishmeal (<1 % of the feed ration) is sometimes used as a protein source and was therefore converted to soybean meal. Due to the insignificant amounts, these conversions were done on a simple kg to kg basis. All mineral supplements were modelled as limestone, as calcium by far is the most quantitative important mineral in these supplements. Vitamin and amino acid supplements were also modelled as limestone due to lack of data on climate impact from such supplements and due to the fact that they are quantitative insignificant, i.e. <1 % of the feed ration.

WHEAT

Wheat was taken from Ecoinvent (2007; "Wheat grains conventional, Barrois, at farm/FR") and was based on French data with a yield of 6753 kg/ha. The inventory included the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering was included. Inputs of fertilisers, pesticides and seed as well as their transports to the farm were considered. The direct and indirect emission of nitrous oxide (N_2O) was also included. The GWP was estimated to 630 g CO_2-eq./kg wheat (Ecoinvent, 2007).

OAT

Oat was only used in the rearing unit and in the hatch egg production. Oat was taken from LCA Food DK (2006) and was based on data with a yield of 4340 kg/ha. The inventory includes fertilisers, machinery, and diesel and energy usage. The direct and indirect emission of N_2O was also included. The GWP was estimated to 553 g CO_2-eq./kg oat (LCA Food DK, 2006).

SOYBEAN MEAL

Soybean meal was taken from Dalgaard et al. (2008) where the GWP was estimated to 721 g CO_2-eq/kg soybean meal delivered in Rotterdam. 92 % of GWP arose from N_2O and 8 % from fossil CO_2 (Dalgaard et al., 2008). An additional GWP was added due to transport from Rotterdam to Aarhus by ship and 50 km transport from Aarhus to feed factory with truck was also included. Thus, the GWP including additional transport by ship and truck was calculated to 738 CO_2-eq./kg soybean meal.

MAIZE

Maize was taken from Ecoinvent (2007; "Grain maize IP, at feed mill/CH"). The inventory included the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering were included. Inputs of fertilisers, pesticides and seed as well as their transports to the farm were considered. The direct and indirect emission of nitrous oxide (N_2O) was also included. The GWP was estimated to 659 g CO_2-eq./kg maize (Ecoinvent, 2007).

RAPE SEED

Rape seed was taken from Ecoinvent (2007; "Rape seed conventional, at farm, Germany") and was based on data with a yield of 3413 kg/ha. The inventory included the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering were included. Inputs of fertilisers, pesticides and seed as well as their transports to the farm were considered. The direct and indirect emissions of nitrous oxide (N2O) were also included. The GWP was estimated to 1330 g CO_2-eq./kg rape seed (Ecoinvent, 2007).

PALM OIL

Palm oil was taken from Ecoinvent (2007; "Palm oil, at oil mill/MY") and was based on an oil mill in Malaysia/Indonesia. The GWP was estimated to 718 g CO_2-eq./kg palm oil and was based on an allocation approach (Ecoinvent, 2007). However, the significance of this process was limited, i.e. <1.5 % of the total GWP/broiler. The inventory included the extraction of palm oil, palm kernel oil and palm kernel meal from palm fruit bunches. Energy supply from extracted solids (fibres, shells, digester solids and empty fruit bunches) and treatment of specific wastewater effluents was taken into account.

MINERALS & VITAMINS

Supplements of minerals, vitamins and amino acids were modelled as limestone ($CaCO_3$) due to lack of data on climate impact from specific supplements. The process included production and packaging (Ecoinvent, 2007; "Limestone, milled, packed, at plant/CH"). The GWP was estimated to 19 g CO_2-eq./kg limestone (Ecoinvent, 2007).

WATER

The usage of water in farms and slaughterhouses was not included if it was retrieved from their own well because the usage of electricity for retrieving water was already included in their total use of electricity. If water was supplied from elsewhere, it was modelled with standard data via the process: "European tap water to end users" (Ecoinvent, 2007).

Energy resources

ELECTRICITY

As no separate energy consumption data were available for the different production lines (e.g. chicken wings, chicken breast, and whole chicken) at the slaughterhouses, the total usage of electricity was held up against the total number of broilers. Marginal electricity was modelled as a mix of existing electricity sources in Denmark (medium voltage) taken from the Ecoinvent database, since it has not been possible to identify one marginal source of electricity. The mix of existing electricity (% of kWh) originates from 48 % coal, 24 % natural gas, 12 % wind power, 11 % oil and 5 % others.

NATURAL GAS

One broiler producer and one Slaughter Company used natural gas for heating purposes and this was modelled as "natural gas burned in boiler low NO_x condensing non-modulating" (Ecoinvent, 2007). In the other slaughter company natural gas was burned in a gas motor (Ecoinvent, 2007) where the electricity was sold to the grid and the heat was distributed as district heat to a local village (see table 4). The following processes were included for natural gas: gas production and transport, infrastructure, emissions to air, substances needed for operation and methane emissions from leakages due to distribution in low pressure network (Ecoinvent, 2007).

DISTRICT HEAT

District heat was used as an energy input by one of the slaughter companies. In the other slaughter company heat was sold during the process of producing electricity from natural gas. The heat sold was assumed to replace district heat, i.e. for this slaughter company, district heat was an avoided production. District heat was modelled by a standard process from the LCA Food database (LCA Food DK, 2006; "district heat").

STRAW

Five out six broiler producers used straw for heating up the broiler-houses. Straw is a by-product from grain production and is therefore produced by the demand of grain and not by a change in demand of straw. Therefore, the GWP of straw itself was considered to have 0 g CO_2-emission. However, the baling (8.9 g CO_2-eq/kg straw) and transportation (assuming an average distance of 2 km) of straw was included via standard data from Ecoinvent (2007; "wheat straw IP, at farm/CH"). It could be argued that carbon from the straw is incorporated into the soil if it stays in the field and thereby function as a carbon sink, but due to lack of estimates this has not been taken into account.

DIESEL

Diesel was only used in small amounts for small machinery in the broiler and hatch egg production. The CO_2 emission was calculated backwards from a standard value for a tractor (including diesel consumption, construction, maintenance, shed etc.) which uses 0.0436 kg diesel per tkm (Ecoinvent, 2007; transport, tractor and trailer/CH"). I.e. the diesel consumption used in the broiler production was converted to tkm in order to include GWP associated with combustion of diesel and manufacturing machinery.

TRANSPORT
Transport was modelled using standard values for a “EURO4 lorry of 16-32 t”, which include fuel consumption, construction, maintenance, road occupation etc. (Ecoinvent, 2007).

Other inputs

SAWDUST
Sawdust was used as bedding material in some of the broiler systems and was modelled as “wood chips” (Ecoinvent, 2007). The process included chopping of residual softwood with a stationary chopper in the sawmill. The GWP was 3010 g CO_2-eq/m^3 wood chips (Ecoinvent, 2007). Assuming 200 kg of wood per cubic metre wood chips, the GWP was estimated to 15 g CO_2-eq/kg sawdust.

SOAP
Different agents were used for cleaning and disinfection in the rearing units, hatch egg production, hatchery, and broiler production in the slaughterhouses. These agents were modelled as soap with a GWP of 1140 g CO_2-eq/kg (Ecoinvent, 2007; “soap, at plant/RER”).

PACKAGING
Packaging materials at the slaughterhouses included foil, plastic containers, cardboard and oxygen. The foil was modelled as “packaging film LDPE”, the plastic containers as “polyethylene”, the cardboard as “corrugated cardboard” and oxygen as “liquid oxygen” using data from the Ecoinvent database (Ecoinvent, 2007). All packaging materials include raw materials, production processes and transport in terms of GWP. Biogenic CO_2 stored in the cardboard was not taken into account (see methods).

COOLING
“Carbon dioxide” was used for cooling purposes at the slaughterhouses and was modelled using data from the Ecoinvent database (Ecoinvent, 2007).

By product: manure

The broiler manure is used as fertiliser in plant production. Due to restrictions on N-supply to crops, the production of broiler manure will decrease the use of artificial fertilizer in plant production. Consequently, the system was expanded to include the avoided production and avoided use of artificial fertilizer. Production of manure will lead to direct and indirect emissions of nitrous oxide (N_2O) and emissions of methane (CH_4), while the use of artificial fertilizer only leads to direct and indirect emissions of N_2O. However, the production of artificial fertilizer requires energy and leads to emission of N_2O and this was also considered.

MANURE - METHANE
During storage of broiler manure, emission of CH_4 occurs. The CH_4 emission was calculated according to the following equation (eq. 10.23 in IPCC (2006)): VS*Bo*MCF*0.67 where VS=volatile solids (=10 g/day according to page 10.82 in IPCC (2006)); Bo=potential share of VS which can be converted to methane (=0.36 according to page 10.82 in IPCC (2006)), MCF=methane conversion factor (=1.5 % according to page 10.82 in IPCC (2006)) and 0.67 is a conversion factor of m^3 CH_4 to kg CH_4. An average production time of 38 days was used. Thus, methane emission was calculated accordingly: 10*38*0.36*0.015*0.67 = 1.37 g CH_4 per broiler.

MANURE – NITROUS OXIDE
Table 5 and 6 gives an overview of the data, calculations and assumptions that have been made in order to estimate the total N_2O emission in a situation with or without broiler manure, when using an inventory

regarding a broiler with a slaughter age of 38 days and a live weight of 2.2 kg excretes app. 60 g N (Poulsen, 2010).

Table 5. Data and calculations on direct and indirect N2O emission from broiler manure. The unit is one broiler.

	g N	g NH_3-N	g NO_3-N	g N_2-N	g N_2O[7]
Ex broiler[1]	60.0				
Ex building[2]	48.0	12.0			0.188
Ex storage[3]	39.4	3.8		4.8	0.060
Applied to soil[4]	35.4	4.0			0.062
Leaching[5]			23.6		0.278
Uptake by plants[6]	11.8				
Indirect N_2O emission[7]					0.589
Direct N_2O emission[8]					0.556
Total N_2O emission					1.145

[1] According to Poulsen et al. (2011)

[2] 20 % of N ex broiler evaporates as ammonia in the farmhouse (Poulsen et al., 2011)

[3] 8 % evaporates as ammonia and 10 % as free nitrogen in the storage (Hansen et al., 2008)

[4] 10 % evaporates as ammonia during application of solid manure to soil (Hansen et al., 2008)

[5] 60 % of applied manure-N to crops is assumed to be leaching based on calculations by Østergaard (2010) using the N-LES3 model (Larsen & Kristensen, 2007). All N leaching is assumed to be converted to NO_3

[6] Calculated as: N applied to crops minus N leaching

[7] Indirect N_2O emission was calculated as 0.75 % of N that was leaching (NO_3; Table 11.3 in IPCC, 2006) and 1 % of N that was evaporating (NH_3; table 11.3 in IPCC, 2006) and converted from N_2O-N to N_2O by a factor of 1.57 (IPCC, 2006)

[8] Direct N_2O emission was calculated as 1 % of N applied to soil (table 11.1 in IPCC, 2006)

Assuming an N-excretion of 60 g/broiler and 39.4 g N ex storage (see table 5) and a utilization of 45 % of N in broiler manure (deep bedding) for plant production (Anonymous, 2011), it can be calculated that manure from one broiler will lead to a reduced usage of ammonium nitrate N-fertilizer by 21.6 g N (39.4-(39.4*0.45)). Table 6 gives an overview of the data, calculations and assumptions that have been made in order to estimate the total N_2O emission if broiler manure was not available.

Table 6. Data and calculations on N2O emission from artificial fertilizer that was substituted by broiler manure. The unit is one broiler.

	g N	g NH_3-N	g NO_3-N	g N_2O[5]
Substituted N[1]	21.6			
Applied to soil[2]	21.4	0.2		0.003
Leaching[3]			8.6	0.101
Uptake by plants[4]	12.9			
Indirect N_2O emission[5]				0.104
Direct N_2O emission[6]				0.336
Total N_2O emission				0.441

[1] 39.4 g N from broiler manure ex storage (see table 5) replaces 21.6 g artificial fertilizer N due to restrictions that defines an N-utilization of 45 % in broiler deep bedding (Anonymous, 2011)

[2] 1 % evaporates as ammonia during application of ammonium nitrate which is the most used artificial fertilizer in DK (Hvid, 2010)

[3] 40 % of applied artificial N to crops is assumed to be leaching based on calculations by Østergaard (2010) using the N-LES3 model (Larsen & Kristensen, 2007). All N leaching is assumed to be converted to NO_3

[4] Calculated as: N applied to soil minus N leaching

[5] Indirect N_2O emission was calculated as 0.75% of N that was leaching (NO_3; table 11.3 in IPCC, 2006) and 1 % of N that was evaporating (NH_3; table 11.3 in IPCC, 2006) and converted from N_2O-N to N_2O by a factor of 1.57 (IPCC, 2006)

[6] Direct N_2O emission was calculated as 1 % of N applied to soil (table 11.1 in IPCC, 2006)

From table 5 and 6 it can be seen that the net N_2O emission is 0.704 g higher when applying broiler manure to the field, corresponding to 210 g CO_2-eq. The substituted 21.6 g N from ammonium nitrate fertilizer corresponds to 188 g CO_2-eq. (see below). Including the methane loss from the broiler manure (see above: 34 g CO_2-eq. due to 1.37g*25) and fossil fuel for spreading manure (6 g CO_2-eq. from the process described below), the production of broiler manure is estimated to contribute with a net GWP of 62 g CO_2-eq./broiler (210+34+6-188).

ARTIFICIAL FERTILIZER

Ammonium nitrate is the most commonly used artificial fertilizer (Sonesson et al., 2009a) and was therefore assumed to be the marginal fertilizer source. Ammonium nitrate has an N content of 32 % and a GWP of 8.7 kg CO_2-eq/kg N (Ecoinvent, 2007), corresponding to 188 g CO_2-eq (21.6 g N * 8.7 kg CO_2-eq/kg N).

SPREADING MANURE

Loading and spreading of 2 kg broiler manure (Poulsen, 2010) was modelled using standard values (Ecoinvent, 2007; "Solid manure loading and spreading, by hydraulic loader and spreader"). The GWP associated with spreading of 21.6 g artificial fertilizer N was assumed to be zero.

By product: poultry waste

WASTE FROM HATCH EGG AND BROILER PRODUCTION

Broiler waste included dead broilers form the broiler farms and egg shells and male chickens from the hatchery which were collected and transported to a destruction site (DAKA). It was assumed that 1 kg broiler waste processed at DAKA could substitute 0.211 kg barley and 0.124 kWh district heat, as these values have been used for other types of animal waste (Dalgaard et al., 2007). Barley and district heat were modelled according to the following:

BARLEY

Barley was taken from Ecoinvent (2007; "Barley grains conventional, Saxony-Anhalt, at farm/DE") and was based on German data with a yield of 7500 kg/ha. The inventory included the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering was included. Inputs of fertilizers, pesticides and seed as well as their transports to the farm were considered. The GWP was estimated to 490 g CO_2-eq./kg barley (Ecoinvent, 2007).

DISTRICT HEAT

District heat was modelled by a standard process from the LCA Food database (LCA Food DK, 2006; "district heat").

WASTE FROM SLAUGHTER HOUSES

Waste from the slaughter houses included discarded broilers, feathers, heads, blood and intestines which were transported to a factory specialised in processing the waste to mink feed (see inventory in table 7). Therefore, the system was expanded to include production of fish meal and maize which were assumed to be the marginal feedstuffs for mink (although fish meal might be a restricted resource due to quotas on fishery, at least in the EU). The amount of poultry waste that was processed to mink feed was 457 g per broiler (see table 4).

Table 7. Inventory for processing slaughter waste to mink feed. One broiler produces 457 g of slaughter waste (feathers, head, blood and intestines).

Transport slaughter waste (kgkm/broiler)[1]	**27**
Electricity (kWh/broiler)	0.016
Gas (MJ/broiler)	0.276

[1] Average distance from the two slaughterhouses to the company that process slaughter waste (0.457 kg*58 km)

From the content of crude protein and energy content in feedstuffs for mink (see table 8), it was calculated that 104 g fish meal and 100 g maize corresponds to 457 g poultry waste in terms of crude protein and metabolizable energy.

Table 8. Content of crude protein (CP) and metabolizable energy (ME) in feeds for mink.

Product	**DM (%)**	**CP (% of DM)**	**ME (MJ/kg DM)**
Poultry waste	31[a]	54.5[a]	21.1[a]
Maize	87[b]	8.4[b]	15.8[c]
Fish meal	92[b]	72.8[b]	16.9[c]

[a] Values are from Clausen (pers. com.)

[b] Values are from Andersen & Just (1990)

[c] ME was calculated according to Andersen & Just (1990)

GWP associated with fish meal and maize is described in the following.

FISH MEAL

"Fish meal" was modelled as produced in conjugation with the by-product fish oil, where 0.21 kg fish oil was produced for each kg fish meal. The fish used for fish meal were assumed 100 % sand eel of which 4.66 kg was used to produce 1 kg fish meal. The GWP for fish meal was 1.01 kg CO_2–eq./kg and included the energy consumption for producing fish meal (LCA Food DK, 2006).

MAIZE

Maize was taken from Ecoinvent (2007; "Grain maize IP, at feed mill/CH"). The inventory included the processes of soil cultivation, sowing, weed control, fertilisation, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering were included. Inputs of fertilisers, pesticides and seed as well as their transports to the farm were considered. The direct and indirect emission of nitrous oxide (N_2O) was also included. The GWP was estimated to 659 g CO_2-eq/kg maize (Ecoinvent, 2007).

Life cycle impact assessment and interpretation

Contributors to Global Warming Potential

The GWP of one broiler packed at the slaughterhouse and ready for shipment was estimated to 3.85 kg CO_2 eq. corresponding to 2.31 kg CO_2 eq. per kg carcass weight using the carcass weight of 1.670 kg.

The different contributors to the GWP are shown in table 9. Roughly, ¾ of GWP arises from the broiler production itself, while 1/8 of GWP arises from the production of hatch eggs (includes rearing unit, parent generation and hatchery) and the last 1/8 arises from the process of slaughtering. The by-product manure increases GWP with 0.06 kg CO_2 eq. per kg carcass weight while the by-product slaughter waste decreases GWP with 0.09 kg CO_2 eq. per kg carcass weight.

Table 9. Contribution to the global warming potential (GWP) when producing 1 Danish broiler.

	kg CO_2 eq.	% of GWP
Hatch egg production[1]	0.52	13.5
Broiler production incl. manure[2]	2.94	76.4
Slaughterhouse[3]	0.39	10.1
Total	3.85	100

[1] including the rearing unit, hatch egg production and hatchery

[2] includes broiler manure which contributes with 0.06 kg CO_2 eq./broiler, i.e. without broiler manure the GWP from the broiler production itself would be 2.88 kg CO_2 eq./broiler

[3] includes slaughter waste which contributes with -0.09 kg CO_2 eq./broiler, i.e. without slaughter waste the GWP from the slaughter process would be 0.48 kg CO_2 eq./broiler

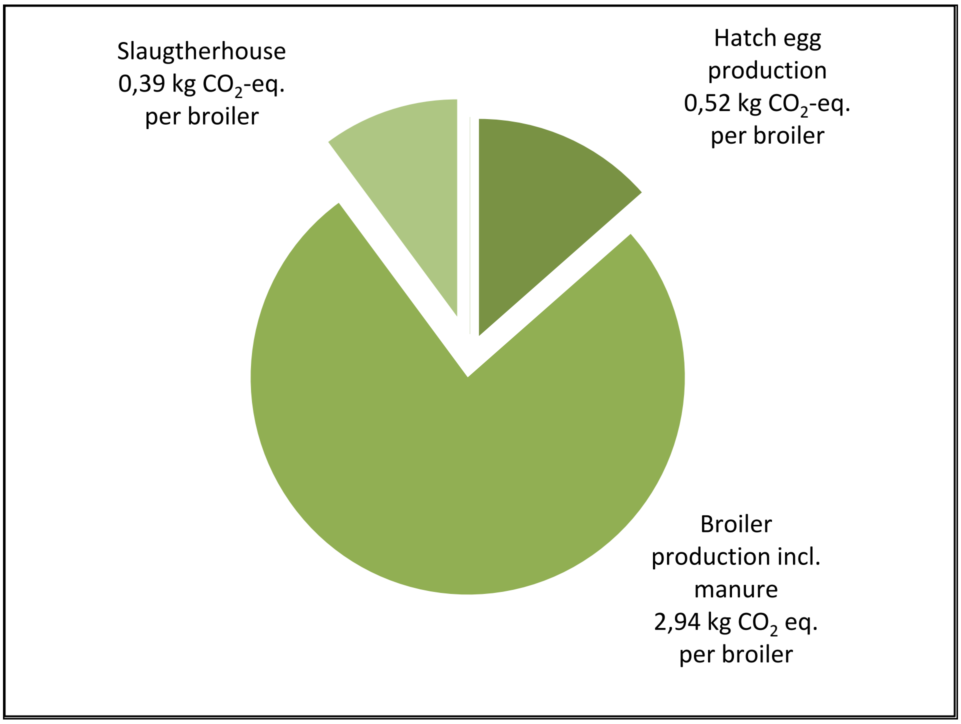

Figure 2. Graphic illustration showing the contribution of the global warming potential (GWP) when producing 1 Danish broiler.

The different contributors to the GWP of the broiler production itself, i.e. without hatch egg production, hatchery, broiler manure and the process of slaughtering, is shown in table 10. Feed is by far the greatest contributor with 91 % of the GWP. From table 2 it is clear that wheat and soybean meal is the quantitatively largest feed components making up 64 % and 23 %, respectively, of the feed ration on an average kg basis. Therefore, the impact of wheat and soybean meal on GWP was further investigated in the section: *"alternative model scenarios".*

Table 10. Contributors to the global warming potential (GWP; 2.88 kg CO_2 eq.) of the broiler production itself, i.e. excl. hatch egg production, hatchery, broiler manure and the process of slaughtering.

	% of GWP from broiler producer
Feed	91
Electricity	4
Gas	2
Other	3

The variation in GWP for broiler producers and slaughterhouses is shown in table 11. The variation between broiler producers is almost entirely due to differences in feed efficiency (kg feed/produced broiler). Two slaughterhouses participated in this investigation and, therefore, the min and max value in table 11 represent the GWP from each of these two slaughter companies.

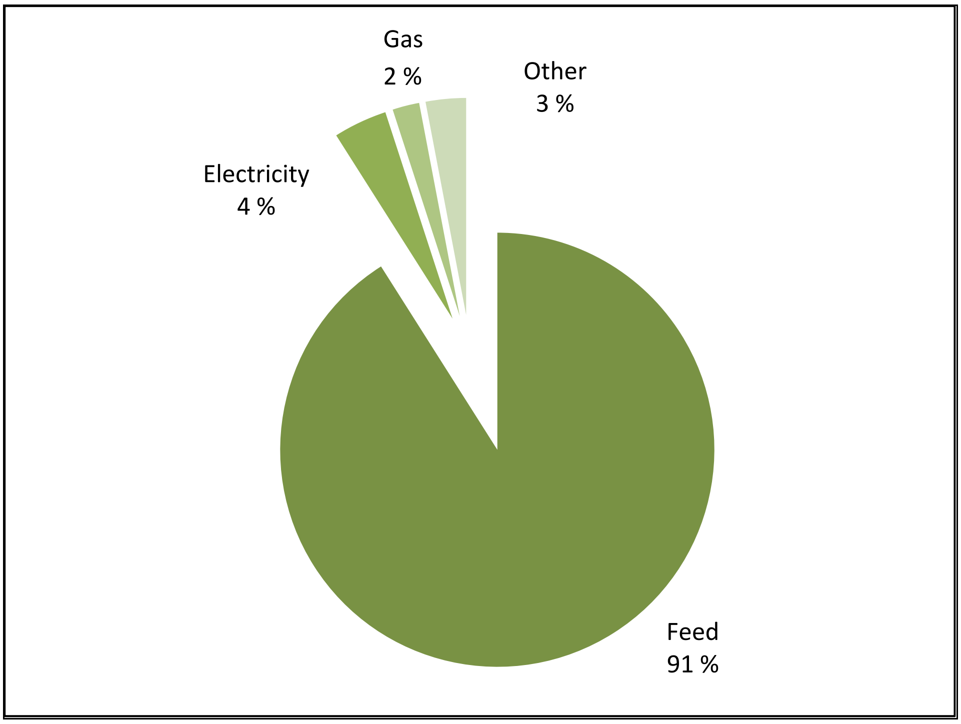

Figure 3. Graphic illustration showing the contribution of the global warming potential (GWP) when producing 1 Danish broiler at the farm.

Table 11. Variation in the global warming potential (GWP) for the 6 broiler producers and the 2 slaughterhouses (kg CO_2 eq. per produced broiler).

	kg CO_2 eq.	**min GWP**	**max GWP**
Broiler production	2.88	2.31	3.30
Slaughterhouse	0.48	0.42	0.55

The contribution from different greenhouse gases to the GWP of a broiler including the production of hatch eggs, hatchery and the process of slaughtering is shown in figure 4.

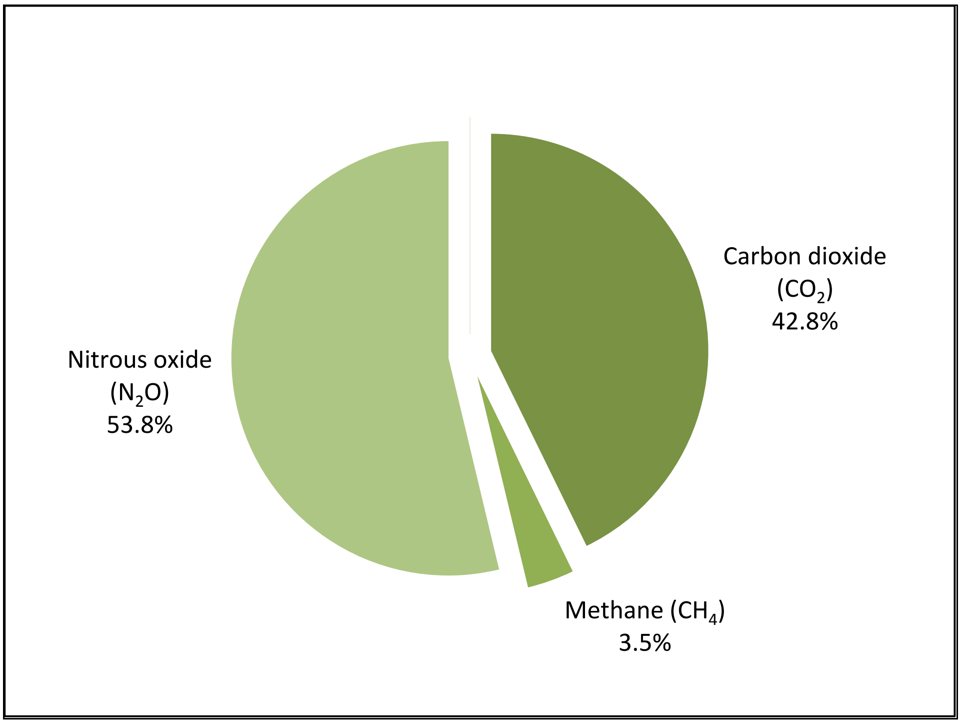

Figure 4. Contribution from different greenhouse gases to the global warming potential of a broiler. The contribution of each gas is calculated in CO_2 equivalents.

Alternative Model Scenarios

In the following a sensitivity analysis of different important factors for the GWP is presented. These include quantitatively important factors such as feed but also artificial fertilizer and the carcass weight have been subjects for sensitivity analysis. As mentioned earlier, feed is by far the greatest contributor with 91 % of the GWP from broiler farms. Wheat and soybean meal is the quantitatively largest feed components making up 64 % and 23 % of the feed ration, respectively.

IMPACT OF WHEAT

The wheat used in this investigation had a GWP of 630 g CO_2-eq./kg but if a German wheat with a GWP of 554 g CO_2-eq./kg (Ecoinvent, 2007) was used instead, the GWP for a Danish broiler would decrease from 3.85 to 3.66 kg CO_2-eq/broiler, i.e. a reduction of 4.9 %. The lower GWP for German wheat is mainly due to higher yields in Germany (7567 kg/ha) compared to France (6753 kg/ha) (Ecoinvent, 2007). LCA studies on Danish wheat shows a GWP of 388 g CO_2-eq./kg wheat as an average of soil types (Hvid, pers. com.).

IMPACT OF SOYBEAN MEAL

The soybean meal used in this investigation had a GWP of 738 g CO_2-eq./kg. But if a value from a new investigation with a GWP of 632 g CO_2-eq./kg (Mogensen, pers. com.) was used instead, the GWP for a Danish broiler would decrease from 3.85 to 3.77 kg CO_2-eq./broiler, i.e. a reduction of 2.1 %. Both LCA's for soybean meal have been made using a consequential approach. However, the way to calculate N_2O emission from nitrogen fixating plants was different and updated according to IPCC (2006) in the LCA made by Mogensen (Mogensen, pers. com.).

IMPACT OF CARCASS WEIGHT

If the heart, liver, feet and neck could not be used for human foods then the carcass weight would be reduced with 181 g/broiler (from 1.670 to 1.489 kg) leading to an increase in GWP from 2.31 to 2.59 kg CO_2-eq/kg carcass weight corresponding to 12 %. There was a difference between the general carcass weight seen in the slaughterhouses (1.670 kg) and the average carcass weight from the six broiler producers (1.755 kg) used in this investigation. Applying the average carcass weight from the six broiler producers leads to a decrease in GWP from 2.31 to 2.19 kg CO_2-eq./kg carcass weight, i.e. a reduction of 5.2 %.

IMPACT OF ARTIFICIAL FERTILIZER

The artificial fertilizer used in this investigation had a GWP of 8.7 kg CO_2-eq./kg N, but modern production of fertilizer has a much lower GWP, i.e. around 4.0 kg CO_2-eq/kg N due to more efficient energy use and less emission of N_2O during the production (Yara, 2010). If a value of 4.0 kg CO_2-eq./kg N was used, it would increase the GWP for a broiler from 3.85 to 3.95 CO_2-eq./kg corresponding to 2.6 %.

Comparisons to other investigations

Few approaches have been made to estimate GWP for broilers and there are a limited number of LCA's in the literature. In Sweden, Thynelius (2008) has published a study on the climate impact from Swedish chicken, which partly is based on an earlier study (Anonymous, 2002). Both these studies are of a "case study" based nature (Sonesson et al., 2009b) and the report is currently under revision and therefore not available (Thynelius, pers. com.) Cederberg et al. (2009) used a "top-down" approach in an LCA study of Swedish production of animal foods, divided into different animal species. However, it is unclear what the poultry category exactly contained and it was therefore not included in the table below.

Table 12 contains an old Danish study (LCA Food, 2006; although the reference says 2006, the data material behind it is at least 10 years old) and a newer Finnish study together with a UK study and the results from the current report. The results from the different studies are presented in the same unit in table 12: kg CO_2-eq per kg bone free meat at the farm gate. However, the results in table 12 are not directly comparable since different methods have been used and different boundaries have been used. But table 12 serves the purpose of showing that the results obtained with the current report seems reasonable.

The UK study by Williams et al. (2006) looked at conventional, free range and organic chicken meat production and this study showed relatively high emissions (see table 12). According to Sonesson et al. (2009b) this higher CO_2 emission can mainly be explained by 3 reasons: 1) an assumption of low N-efficiency in the broiler manure and therefore high N_2O emission and low substitution of artificial fertilizer, 2) low efficiency and high usage of fossil fuels in feed production and 3) a high usage of fossil fuels in the heating of broiler houses. Table 12 shows that the GWP of Danish chicken meat is within the same level as found in other LCA studies with the same production type.

Table 12. Emissions of greenhouse gases per kg bone free chicken meat at the farm gate.

		Kg CO_2-eq per kg bone free meat		
Study	Total	CH_4	N_2O	CO_2
LCA Food (2006)[1,3]	3.4	0.1	2.0	1.3
Katajajuuri (2007)[2]	2.7	0.4	1.0	1.3
Williams et al. (2009)[3,4]	3.4			
Williams et al. (2009)[3,5]	3.9			
Williams et al. (2009)[3,6]	5.1			
Nielsen et al. (2011), i.e. this study)[7]	3.0	0.1	1.8	1.1

[1] Results (1.82 kg CO_2 eq./kg live weight) converted from live weight to carcass weight with a factor of 70 %

[2] The functional unit was broiler fillet which was assumed to correspond to bone free meat

[3] Results converted from carcass weight to kg meat with 77 % cutting-out from carcass weight to bone free chicken meat (Sonesson et al., 2009b)

[4] Conventional production

[5] Free range production

[6] Organic production

[7] Results in this report was converted from carcass weight (1489 g) to kg meat with 77 % cutting-out from carcass weight to bone free meat, i.e. per broiler 1147 g of bone free chicken was produced (1489*0.77). The GWP from the hatch egg production was included but the GWP from the slaughterhouse was excluded in order to make results in table 5 comparable at the farm gate.

Conclusion

The GWP of one broiler packed at the slaughterhouse and ready for shipment was estimated to 3.85 kg CO_2 eq. per broiler corresponding to 2.31 kg CO_2 eq. per kg carcass weight. The broiler production itself was the greatest contributor to GWP with 76.4 %. The hatch egg production, incl. rearing unit and hatchery contributed with 13.5 % of the GWP and the slaughter process with 10.1 %. Nitrous oxide, CO_2 and methane contributed with 54, 43 and 3 % of the CO_2 eq., respectively.

Sensitivity calculations have shown that the GWP of broilers is most sensitive to the data used for wheat and the carcass weight.

The large variation in feed efficiency between Danish broiler producers emphasize that the largest potential for reducing GWP here and now is to improve feed efficiency. The large variation in feed efficiency observed between Danish broiler producers despite virtually same level of feed quality available across houses and farms emphasize that the largest potential for reducing GWP here and now is to focus on intensified management and daily working routines in order to improve both weight gain and feed efficiency at the individual broiler producer in order to reduce GWP input in broiler production. The GWP of Danish chicken meat is within the same level as found in other LCA studies.

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Critical review of the report:
'Greenhouse Gas Emissions from the Danish Broiler Production estimated via LCA Methodology'

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Review procedure
The review was performed as a three step review in the period from 10 February 2011 to 6 June 2011. The review was carried out by one single reviewer and not by a panel of interested parties. Consequently, the results must not be used to support a comparative assertion intended to be disclosed to the public. The reviewer has commented on five different versions of the report, and all comments from the reviewer were written directly in the report. It should be emphasized, that the reviewer is not an expert in broiler production.

Overall
The study was conducted in accordance with the ISO 14040 and 14044 standards and the overall impression of the report is good quality. In general the report is logical in its structure and easy to understand.

Purpose of the study
The purpose of the project was to gain knowledge about greenhouse gas emissions from the Danish broiler production. More specifically the aims were to:

(1) Quantify the global warming potential (GWP) of Danish broilers and

(2) Identify products/processes with a major contribution to GWP of Danish broilers.

The report supports the purpose and aims well.

Methodology
The Life Cycle Assessment of broiler production was based on the consequential approach, and thereby allocation was avoided. System expansion was used to include the consequences of producing the by-products manure and poultry waste. Characterization factors were derived from the life cycle impact assessment (LCIA) method 'IPCC 2007 GWP 100A' which is based on data from Intergovernmental Panel on Climate Change.

The above mentioned methodologies are well recognized internationally.

Data quality
Data on inputs and outputs to 'Hatch egg production', 'Hatchery', 'Broiler production' and 'Slaughtering and packaging' were supplied by Knowledge Centre for Agriculture, Poultry (in Denmark) and were based on two rearing units (of future hens for hatch egg production), two hatch egg producers, one hatchery, six broiler producers and two poultry slaughterhouses. Data seems to be high quality and were considered to represent the inputs and outputs to the Danish broiler sector in a reasonable way.

The feed input to the broiler production was the largest contributor to greenhouse gas emissions. LCI data on feed were primarily from Ecoinvent (2007). The palm oil data used in the calculations were mass allocated, which not was in line with the consequential approach. However, only a minor amount of palm oil was used per broiler and the contribution to greenhouse gas emission was very low. So although consequential data were used for palm oil, it would not have changed the conclusions.

The carcass weight had a relatively large impact on the result. It was decided to use the carcass weight from the slaughterhouse, which resulted in higher greenhouse gas emissions per broiler compared to a calculation using average data from the six broiler producers.

All data in the report are of high quality, well documented and presented in a structured way.

Impact assessment

The presented impact assessment category is global warming, which is in line with the purpose of the report. Furthermore, greenhouse gas emitted due to land transformation (from forest to arable land) was not included in this study due to lack of common methodology.

Sensitivity analyses, interpretation and conclusion

Sensitivity analyses were performed on the most relevant parameters including wheat, soybean meal, carcass weight and artificial fertilizer. The result was most sensitive to carcass weight. Furthermore, a comparison to other studies showed that greenhouse gas emissions from the study were at same level as found in other LCA studies with equal production type.

Conclusion

The study is performed in accordance with the ISO 14040 and 14044 standards.

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