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# Greenhouse Gas Emission from Danish Organic Egg Production estimated via LCA Methodology

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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 organic eggs produced at Danish farms. Furthermore, to identify the hot spots of the products/processes with major contributions to the GWP of Danish organic eggs. The functional unit was 1 kg of eggs ready for transport to the egg packing station, i.e. at the farm gate. Data was collected from two rearing units and five egg producers. This study therefore includes GWP from the rearing unit, the egg production unit and all internal and external transports. No further GWP after the egg production was included.

**Methods**

The GWP estimates in this study are based on a consequential approach using system expansion. The main by-products were manure and dead egg-layers and the system was therefore expanded to include the avoided production of artificial fertilizer, despite an organic system, and mink feed, 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 such as buildings, machinery etc. was in general not included.

**Results**

An average egg weighs 62 gram and therefore 1 kg of eggs is equivalent to 16.1 eggs. The variation among egg producers was from 59.5 to 66.6 gram.

The GWP of 1 kg eggs at the farm gate was estimated to 1.80 kg $CO_2$ eq, i.e. 112 g $CO_2$ eq per egg.
The production of pullets contributed with 15 % of GWP while the production of eggs contributed with 85 %. At egg producer level the major contributor to GWP was feed with 76 % of GWP. Minor contributors were electricity (12 %), manure (8 %), diesel (2 %) and other (2 %).

The variation between egg producers ranged from 1.34 to 1.86 kg $CO_2$ eq. per kg eggs. The GWP/kg eggs was highly correlated to the feed efficiency, defined as kg feed/kg eggs, i.e. the higher feed efficiency, the lower GWP.

**Conclusions**

The relatively large variation in feed efficiency between Danish organic egg producers emphasize that the biggest potential for reducing GWP in the short term, is to improve feed efficiency.

## BACKGROUND OF LCA

A Life Cycle Assessment (LCA) is the assessment of environmental effects, 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 faith 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 fabrication 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 was to (1) quantify the global warming potential (GWP) of Danish organic egg production and (2) to identify products/processes with a major contribution to GWP of the egg production.

The focus of the report is to identify sources of global warming potential of Danish organic egg production; other environmental impacts are not covered in this report.

The results of this study are for use within a Danish project called “Climate friendly poultry production” where partners and industry within the conventional broiler production and organic egg production has participated. The partners in relation to the organic egg production includes Organic Farming Association (Økologisk Landsforening) and Knowledge Centre for Agriculture, Poultry together with egg- and pullet producers, where the data has been collected. The purpose of the project is to gain knowledge about the GWP of Danish organic egg production. The results are not to be used as a comparative assertion (ISO, 2006).

This report has been critically reviewed by an external LCA-expert.

### Functional Unit

The functional unit in this report is 1 kg of eggs ready for transport to the egg packing station, i.e. at the farm gate, and thus no further GWP after the egg producing unit was included in this study. The average weight of an organic egg is 62 gram (Jørgensen, 2011) and therefore 1 kg of eggs is equivalent to 16.1 eggs.

### Data

Data from two rearing units and five egg producers were supplied by Knowledge Centre for Agriculture, Poultry. The 5 organic egg producers were randomly drawn from a list in which all 58 organic egg producers in Denmark were listed. There are five rearing units (breeding herds) in Denmark and the two used in this study were selected due to the fact that they delivered the animals to the five organic egg producers (Jørgensen and Rasmussen, pers. com.). The data collected was from 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 are made using the PC tool SimaPro 7.1 (PRé Consultants, 2008) together with LCA databases (Ecoinvent (2007) and LCA Food DK (2006)) 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 eggs is not included, the LCA reported here excludes biogenic $CO_2$ sources. Furthermore, GWP that arises due to land transformation is 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 is 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.) are included in the basic data in the Ecoinvent database (Ecoinvent, 2007). However, buildings at the production facilities (farmhouses, storage houses, etc.) were not included, because they are expected to be of minor importance.

APPROACH

The LCA reported here is based on a consequential approach (CLCA), but many of the processes used, such as EcoInvent, are made via allocation (ALCA). Therefore, a combination of CLCA and ALCA is used in this report. In many processes more than one product is produced (joint production). In such cases it is necessary to divide the environmental impact from the process between the products (the main product and by-products). This is done by *system expansion*, where the impacts of the by-products are 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 implies marginal data for a given product and a marginal supplier is characterised as being able to increase its production at an economic favourable price (Reinhard & Zah, 2011). Thus CLCA has two important features: 1) it tries to model the processes that are influenced by a change in demand 2) allocation of by-products is avoided by system expansion.

SYSTEM DESCRIPTION

This investigation includes greenhouse gases emitted from the rearing unit (of future hens for egg layer production) and the egg production unit together with all internal and external transports. For more details, see section on *Process description*.

SYSTEM BOUNDARIES

In this assessment the lower boundary is the rearing unit where pullets grow up until the age of 18 weeks. The upper boundary is the eggs at the production units ready for transport to the egg packing station. The boundaries and inputs/outputs are visualized in Figure 1. Due to the production of by-products, the system was expanded to include the avoided production of artificial fertiliser and mink feed due to the egg layers production of manure and discarded egg layers, respectively. Despite the organic system, it was assumed that the marginal fertilizer will be artificial fertilizer. No data was available for the “parent generation” and the hatch egg industry and the GWP contribution from these units were expected to be of very little magnitude.

At all five egg production units, some wheat was home-grown. However, the focus in the project was to identify what can be done in the egg 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 whether it was bought from a feed stuff company or home-grown.

**Process description**

An overview of the flow diagram of organic egg production is given in Figure 1. The following inputs are used in the egg production: pullets, feed, water, electricity, diesel fuel, bedding material and transport. In the first 17-19 weeks of the rearing pullet’s life, they are housed in a rearing house. After this period they are moved from the rearing house to a hen stable where they lay eggs for app. 12 months.

The by-products from the egg production are manure and dead/discarded hens. Therefore, the system was expanded to include the avoided production of artificial fertiliser due to the manure production. Egg layers that died during the production period were transported to DAKA where they were assumed to be processed to heat and feed, i.e. district heat and barley, respectively (Dalgaard et al., 2007). The production period ended for the egg layers after app. 12 months where the egg layers were either transported to Germany to be slaughtered or they were euthanized and used for mink feed. If they were used for mink feed the hens were chopped up at the farm and transported to a factory for further processing to mink feed. Because the faith of the hens in Germany is unclear it was decided to model hens from the 5 production units as being processed to mink feed (see *Inventory section*).

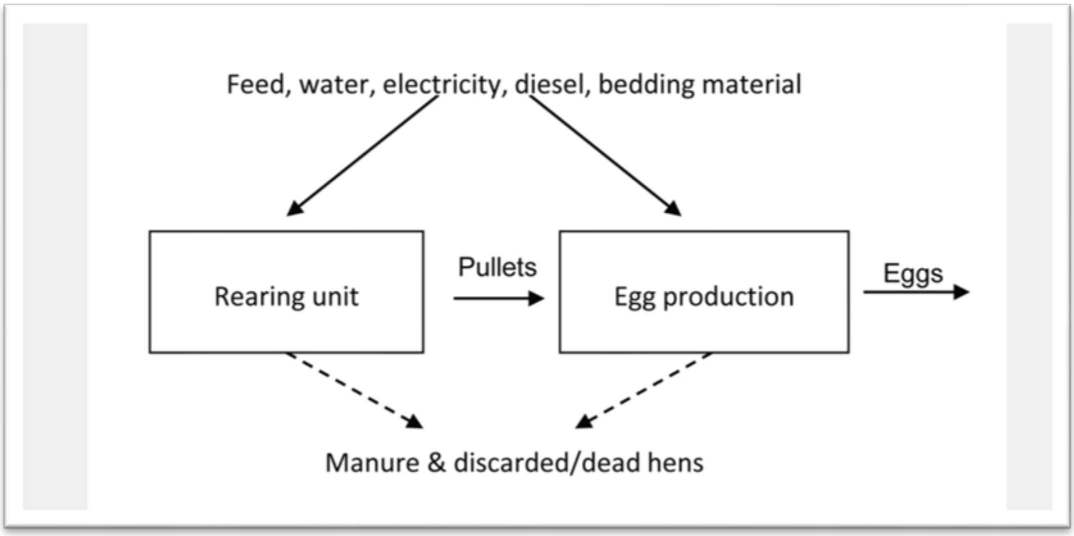


**Figure 1.** Main flow diagram in egg production. Boxes illustrate processes, arrows illustrate inputs from outside and transport from one process to another. From each process there is by-products indicated by dashed arrows. The quantitatively major by-products are manure and discarded hens which are used as fertiliser and mink feed, respectively. The quantitatively minor by-products are dead hens which are processed at DAKA.

## LIFE CYCLE INVENTORY

All data presented in the following are from 2009 and were supplied by Knowledge Centre for Agriculture, Poultry (Jørgensen and Rasmussen, pers. com.). The inventory is based on 2 pullet rearing units and 5 egg producers. In the following Table 1 and 2, the inventory is described for the rearing units and the egg production units.

Table 1 presents the inventory for the production of one pullet which is ready for delivery to the egg producer at the age of 18 weeks. The data was collected from two pullet rearing units and the average of those two is presented in Table 1.

**Table 1.** Inventory for production of 1 pullet based on data collection from 2 Danish organic rearing units. The unit is "g per pullet" unless otherwise stated.

| | **Rearing unit** |
|---|---|
| Transport feed (kgkm/pullet)[1] | 1,361 |
| Wheat | 3,489 |
| Sunflower cake | 390 |
| Soybean cake | 106 |
| Maize gluten[2] | 15 |
| Barley | 372 |
| Maize | 712 |
| Soybeans | 58 |
| Oat | 629 |
| Rape seed cake[2] | 544 |
| Peas | 236 |
| Fish meal | 363 |
| Potato protein | 86 |
| Green meal | 220 |
| Supplements[3] | 218 |
| Total feed | 7,438 |
| Water (L/pullet) | 13.8 |
| Electricity (kWh/pullet) | 0.51 |
| Oil (L/pullet) | 0.29 |
| Waste for DAKA[4] | 22 |
| | |

[1] includes transport of feed from feed company to rearing unit (7.438 kg feed/pullet*183km = 1,361 kgkm/pullet)
[2] conventional feedstuffs include maize gluten and rapeseed cake, while the remaining feedstuffs are organic
[3] supplements include minerals and vitamins
[4] include dead birds from the production
[5] GWP for feedstuffs (g $CO_2$ eq/kg feedstuff), see details in the *Feed section* below

Table 2 presents the inventory for the production of 1 kg of eggs based on data collected from 5 Danish organic egg producers. The data was collected for the year 2009. The variation is illustrated by minimum and maximum values. The average values and variation on feed usage per kg egg are in accordance with other investigations and are therefore representative (Rasmussen, pers. com.).

**Table 2.** Inventory for production of 1 kg of eggs based on data collection from 5 Danish organic egg producers. The unit is "g per kg eggs" unless otherwise stated.

| | **Average** | **Min** | **Max** | **GWP[10] (kg $CO_2$-eq./ resource)** |
|---|---|---|---|---|
| Transport pullets (kgkm/pullet)[1] | 157 | | | 0.000153 |
| Pullets/kg eggs | 0.059 | 0.046 | 0.071 | |
| Transport feed (kgkm/kg eggs)[2] | 275 | | | 0.000153 |
| Wheat | 1167 | 970 | 1317 | 0.322 |
| Sunflower cake[3] | 119 | 0 | 216 | - |
| Soybean cake | 229 | 160 | 416 | 0.357 |
| Maize gluten[4] | 111 | 91 | 143 | 1.102 |
| Barley | 78 | 6 | 176 | 0.341 |
| Maize | 266 | 116 | 483 | 0.438 |
| Soybeans | 178 | 26 | 348 | 0.429 |
| Oat | 75 | 0 | 141 | 0.341 |
| Rape seed cake[4] | 25 | 0 | 65 | 0.302 |
| Peas | 59 | 0 | 165 | 0.236 |
| Oyster shells | 104 | 81 | 156 | 0 |
| Fish meal | 71 | 54 | 99 | - |
| Green meal | 84 | 27 | 227 | 1.019 |
| Supplements[5] | 186 | 154 | 220 | 0.019 |
| Silage[6] | 89 | 32 | 172 | 0.167 |
| Total feed (kg/kg eggs) | 2.841 | 2.376 | 3.536 | |
| Water (L/kg eggs) | 5.0 | 3.2 | 8.1 | 0.000318 |
| Electricity (kWh/kg eggs) | 0.32 | 0.13 | 0.57 | 0.56 (kWh) |
| Bedding - straw | 88 | 0 | 182 | 0.009 |
| Bedding – sand | 41 | 0 | 150 | 0.002 |
| Diesel (L/kg eggs) | 0.007 | 0.003 | 0.01 | 3.9 (L) |
| Waste for DAKA[7] | 4 | 2 | 5 | 0.490 (Kg barley)<br>0.0027 (MJ distinct heat) |
| By-product for mink feed[8] | 91 | 82 | 103 | 1.01 (kg fish meal)<br>0.659 (kg maize) |
| Manure[9] | | | | 0.119 |

[1] includes average transport of pullets from a rearing unit to an egg producer. Average weight of 1 pullet estimated to 1.3 kg (1.3 kg pullet*121km = 157.3 kgkm)
[2] includes average transport of feed from feed company to egg producer (2.752 kg feed/kg eggs*100km = 275.2 kgkm/kg eggs)
[3] Sunflower cake and fish meal replaced by soybean cake because this is the marginal protein resource. *See feed section.*
[4] conventional feedstuffs include maize gluten and rapeseed cake, while the remaining feedstuffs are organic
[5] supplements include minerals and vitamins
[6] silage was used in all production units and was not included in the amount of "total feed"
[7] include dead birds from the production and can be replaced by barley and distinct heat *(See Waste section)*
[8]after end production period birds were processed to mink feed. Mink feed replaced by fish meal and maize (*see section by-products*).
[9]Difference between manure fertilizer and artificial fertilizer (see table 5 in LCA Inventory section).
[10] GWP for resources measured in kg $CO_2$-eq/ kg resource unless other is stated. See details for estimation of GWP for each resource in the following sections.

**Feed**

The consequential approach has been 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 (Dalgaard, pers. com.) (See meaning of "marginal" under *Methods*) unless they are originating from a constrained production. This is the case for sunflower cake which is not produced by the demand for sunflower cake but only for the demand of sunflower oil (Weidema, 1999). Thus, the marginal organic protein source was assumed to be soybean cake based on the substantially increase in import to Denmark during the last few years (Knudsen et al., 2010). Therefore, sunflower cake was converted to soybean cake on a kg to kg basis due to the fact that the two feedstuffs contain roughly the same amount of crude protein (Anonymous, 2011a). Like sunflower cake, fishmeal is also used as a protein source in the feed ration for egg layers and comes from a constrained production due to fish quotas. Fishmeal, which only makes up 2.5% of the ration, was therefore converted to soybean cake. Oyster shells are a calcium source for egg layers and arise from a constrained production due to fish quotas. However, oyster shells are considered as a waste product and therefore no GWP is "attached" to them except for the transport from the fishing industry to the egg producer.

Due to the fact that oat was only used in small amounts, i.e. 2.5% of the feed ration; oat was converted to barley on a kg to kg basis. All mineral supplements were modelled as limestone, as limestone is by far the most quantitatively important ingredient in these supplements. Vitamin and enzyme 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 quantitatively insignificant, i.e. <1% of the feed ration.

FEED MANUFACTURING

Based on data from Ecoinvent (2007), a Swedish study (Lantmannen, 2011) and a Swiss study (Baumgartner et al., 2008) it was decided to use a value of 55 g $CO_2$ per kg feed due to the processing of single feedstuffs into pellets.

WHEAT

Organic wheat was taken from Mogensen et al. (2011) which is based on Danish data with a yield of 3600 kg/ha. The inventory includes diesel usage for machinery, electricity for watering, fertilizers etc. The direct and indirect emission of nitrous oxide ($N_2O$) was included. The GWP was estimated to 322 g $CO_2$-eq/kg wheat.

SOYBEAN CAKE

Organic soybean cake was modelled using organic soybeans from China which were estimated to have a GWP of 429 g $CO_2$-eq/kg soybeans when delivered in Aarhus by ship (Knudsen et al., 2010). 33% of the GWP from organic soybeans arose from $N_2O$ and 67% from fossil $CO_2$ (Knudsen et al., 2010).

When producing soybean cake, soybean oil arise as a co-product and 1.25 kg of soybeans can be processed to 1 kg soybean cake and 0.25 kg soybean oil (Dalgaard et al., 2008), i.e. 1 kg soybeans gives 0.8 kg cake and 0.2 kg oil. Palm oil has been identified as the marginal vegetable oil (Schmidt & Weidema, 2008) and 0.2 kg of palm oil was therefore assumed to be substituted with soybean oil. Palm oil was taken from Ecoinvent (2007) and had a GWP of 718 g $CO_2$-eq/kg. Thus, the GWP for organic soybean cake was estimated to 357 g $CO_2$-eq/kg cake ((429-0.2*718)*1.25).

MAIZE GLUTEN

Maize gluten is used as a conventional feedstuff for egg layers and its GWP was taken from Flysjö et al. (2008). The estimated GWP was based on economic allocation and resulted in a GWP of 1102 $CO_2$-eq/kg maize gluten.

BARLEY

Organic barley was taken from Mogensen et al. (2011) which is based on Danish data with a yield of 3200 kg/ha***.*** The inventory includes diesel usage for machinery, electricity for watering, fertilizers etc. The direct and indirect emission of nitrous oxide ($N_2O$) was included. The GWP was estimated to 341 g $CO_2$-eq/kg barley.

MAIZE

Organic maize was taken from Ecoinvent (2007; "Grain maize organic, at farm/CH"). A fresh matter yield of 7777 kg/ha was used based on data collection from the years 1996-2003 in the Swiss lowlands. The inventory includes 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 are included. Inputs of fertilizers and seed as well as their transports to the farm are considered. The direct and indirect emission of nitrous oxide ($N_2O$) was also included. The GWP was estimated to 438 g $CO_2$-eq/kg maize (Ecoinvent, 2007). It was assumed that the organic maize is grown in Denmark and therefore no additional transport from e.g. southern Europe was included.

SOYBEANS

Organic soybeans were modelled as organic soybeans from China which were estimated to have a GWP of 429 g $CO_2$-eq/kg soybean when delivered in Aarhus by ship (Knudsen et al., 2010). 33% of the GWP from organic soybeans arose from $N_2O$ and 67% from fossil $CO_2$ (Knudsen et al., 2010).

RAPE SEED CAKE

Rape seed cake is used as a conventional feedstuff for egg layers and was taken from Mogensen et al. (2011). The inventory includes the growing of and the processing of rape seeds into oil and cake. A yield of 3590 kg/ha was used. The inventory includes diesel usage for machinery, electricity for watering, fertilizers etc. The direct and indirect emission of nitrous oxide ($N_2O$) was included. An economic allocation was used with 76 for the oil and 24% for the cake. The GWP was estimated to 302 g $CO_2$-eq/kg rape seed cake (Mogensen et al., 2011).

PEA

GWP value for peas was taken from Flysjö et al. (2008) where the GWP was estimated to 236 g $CO_2$-eq/kg pea.

GREEN MEAL

Organic green pellets was taken from Mogensen et al. (2011) which is based on Danish data with a grass yield of 7875 kg DM/ha. The inventory includes diesel usage for machinery, electricity for watering, fertilizers etc. and the drying process. The direct and indirect emission of nitrous oxide ($N_2O$) was included. The GWP was estimated to 1019 g $CO_2$-eq/kg pellets.

MINERALS & VITAMINS

Supplements of minerals and vitamins and oyster shells were modelled as limestone ($CaCO_3$) due to lack of data on climate impact from specific supplements and shells. The process includes 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).

SILAGE

The inventories include the organic production of grass for silage from 40% natural intensive meadows, 40% natural extensive meadows and 20% temporary meadows. Included steps are soil cultivation, fertilisation (slurry and manure), harvest, baling, loading and transport. The GWP was estimated to 167 g $CO_2$-eq/kg DM silage (Ecoinvent, 2007).

WATER

The usage of water in farms was not included if it was retrieved form 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

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 37% coal, 20% natural gas, 14% wind power, 3% oil and 8% others (cogen, biogas, a.o.) in Denmark plus 8% Swedish, 7% German and 3% Norwegian electricity mix. This mix was taken from Nord Pool Spot A/S (www.nordpoolspot.com). GWP was estimated to 0.56 kg $CO_2$-eq.(Ecoinvent, 2007).

DIESEL

Diesel used for machinery in the egg layer farmhouse was included. The $CO_2$ emission from diesel fuel combusted is 107g $CO_2$-eq/MJ (LCA Food DK, 2006). The process includes combustion of diesel in tractor with average load and also includes a rough estimate of energy consumption associated with producing and disposing the tractor. Assuming an energy content of 42.8 MJ/kg diesel and a diesel density of 0.85 kg/L, the GWP for 1 L diesel was calculated to 3.9 kg $CO_2$-eq.

TRANSPORT

Transport is modelled using standard values for a “EURO4 lorry of 16-32 t”, which includes fuel consumption, construction, maintenance, road occupation etc. (Ecoinvent, 2007). GWP was estimated to 0.000153 kg $CO_2$-eq. /kgkm (Ecoinvent, 2007).

**Other inputs**

STRAW FOR BEDDING

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 is 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 is included via standard data from Ecoinvent (2007; “wheat straw IP, at farm/CH”). It can 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.

SAND FOR BEDDING

Sand is used as bedding material and was modelled as “sand” (Ecoinvent, 2007). It includes the whole manufacturing process for digging of gravel round and sand, internal processes (transport, etc.), and infrastructure for the operation (machinery). The GWP was estimated to 2 g $CO_2$-eq/kg sand (Ecoinvent, 2007).

**By product: manure**

The manure from egg layers is used as fertiliser in plant production. Due to restrictions on N-supply to crops, the production of egg layer manure will decrease the use of artificial fertilizer in plant production. Despite the organic egg production system, it was assumed that the marginal fertilizer in question would be artificial fertilizer. 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 artificial fertilizer leads to direct and indirect emissions of $N_2O$ and requires energy for its production.

MANURE - METHANE

During storage of egg layer manure, emission of $CH_4$ occurs. The $CH_4$ emission is calculated according to the following equation (eq. 10.23 in IPCC (2006)): VS*Bo*MCF*0.67 where VS=volatile solids (=20 g/day according to page 10.82 in IPCC (2006)); Bo=potential share of VS which can be converted to methane (=0.39 according to page 10.82 in IPCC (2006)), MCF=methane conversion factor (=1.5% at an annual average temperature of 12°C for dry manure according to page 10.82 in IPCC (2006)) and 0.67 is a conversion factor of $m^3$ $CH_4$ to kg $CH_4$. A production time of 365 days per egg layer was used and the methane emission was calculated accordingly: 20*365*0.39*0.015*0.67 = 28.6 g $CH_4$ per egg layer or 1.64 g $CH_4$ per kg eggs due to the fact that one egg layer produces 17.4 kg eggs/year in average according to the production data from the 5 organic egg producers.

MANURE – NITROUS OXIDE

Table 3 and 4 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 egg layer manure. An egg layer´s excretion of N is calculated according to the feed consumption, the protein content in the feed, the egg production and the daily gain of the egg layer (Poulsen, 2011). In average of the 5 egg producers, 32.8 g N per kg eggs (variation from 19 to 48 g N per kg eggs between producers) was excreted. According to Poulsen (2011) 83 % of the excretion takes place in the farm house and 17% in the outdoor area. In the calculations made in Table 3, the same direct $N_2O$-emission and leaching of N was assumed, whether the manure was excreted in the outdoor area or collected in the farm house and spread on the field.

**Table 3.** Data and calculations on direct and indirect $N_2O$ emission from egg layer manure. The unit is per kg of eggs.

| | g N | g $NH_3$-N | g $NO_3$-N | g $N_2O$[9] |
|---|---|---|---|---|
| *Ab* egg layer[1] | 32.8 | | | |
| *Ab* building & storage[2] | 14.1 | 18.7 | | 0.293 |
| Applied to soil[3] | 12.7 | 1.4 | | 0.022 |
| Leaching[4] | | | 7.6 | 0.090 |
| Uptake by plants[5] | 5.1 | | | |
| Indirect $N_2O$ emission[6] | | | | 0.405 |
| Direct $N_2O$ emission - storage[7] | | | | 0.051 |
| Direct $N_2O$ emission - field[8] | | | | 0.199 |
| Total $N_2O$ emission | | | | 0.655 |

[1] Calculated for each egg producer and corrected for amount of feed and protein content in the feed according to Poulsen (2011)
[2] 57% of N *ab* egg layer evaporates as ammonia in the farmhouse and from storage in organic systems with deep bedding, manure pits and outdoor area (Poulsen, 2011)
[3] 10% evaporates as ammonia during application of solid manure to soil (Hansen et al., 2008)
[4] 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 $NO_3$
[5] Calculated as: N applied to soil minus N leaching
[6] Calculated as the sum of indirect $N_2O$ from $NH_3$ and $NO_3$
[7] Direct $N_2O$ emission was calculated as 0.1% of N *ab* egg layer (Table 10.21 in IPCC, 2006)
[8] Direct $N_2O$ emission was calculated as 1% of N applied to soil (Table 11.1 in IPCC, 2006)
[9] 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). $N_2O$-N was converted to $N_2O$ by a factor of 1.57 (IPCC, 2006)

In Denmark, the N in manure that is spread on the fields has to be utilised with a certain percentage depending on manure type. N in deep bedding manure from egg layers has to be utilized with 45% whereas N excreted in the outdoor area and in the pits inside the farm house has to be utilised with 65% (Anonymous, 2011c). According to Poulsen (2011) 33% of the N excretion takes place in the deep bedding and 67% in the pits and outdoor area. Thus, the combined N-utilisation of egg layer manure from this housing system is 58.4% (45*0.33+65*0.67). With the estimated N-excretion 14.1 g N per kg eggs ab storage (see Table 3), it can be calculated that manure from the production of one kg eggs will lead to a reduced usage of 8.2 g N from artificial N-fertiliser (14.1*0.584). Table 4 gives an overview of the data, calculations and assumptions that have been made in order to estimate the total $N_2O$ emission if egg layer manure was not available.

**Table 4.** Data and calculations on $N_2O$ emission from artificial fertilizer that was substituted by egg layer manure. The unit is per kg of eggs.

| | g N | g $NH_3$-N | g $NO_3$-N | g $N_2O$[5] |
|---|---|---|---|---|
| Substituted N[1] | 8.2 | | | |
| Applied to soil[2] | 8.1 | 0.1 | | 0.001 |
| Leaching[3] | | | 3.2 | 0.038 |
| Uptake by plants[4] | 4.9 | | | |
| Indirect $N_2O$ emission[5] | | | | 0.039 |
| Direct $N_2O$ emission[6] | | | | 0.128 |
| Total $N_2O$ emission | | | | 0.168 |

[1] 14.1 g N from egg layer manure ab storage (see Table 3) replaces 8.2 g artificial fertilizer N due to restrictions that defines an N-utilization of 58.4% in egg layer systems with deep bedding, manure pits and outdoor area (Anonymous, 2011c)
[2] 1% of N 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 3 and 4 it can be calculated that the net $N_2O$ emission from egg layers is 0.487 g/kg eggs (0.655-0.168) corresponding to 145 g $CO_2$-eq. However, when manure is substituting artificial fertilizer, the production of the artificial fertilizer itself also has to be taken into account as well as the fossil fuel for spreading egg layer manure. The inventory for this is considered in the following two paragraphs.

PRODUCTION OF ARTIFICIAL N FERTILISER

Ammonium nitrate is the most common used artificial fertilizer (Sonesson et al., 2009) 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 71 g $CO_2$-eq/kg eggs (8.2 g N/kg eggs * 8.7 g $CO_2$-eq/g N). This GWP is only referring to the production of the fertilizer itself.

SPREADING MANURE AND FERTILISER

Loading and spreading of egg layer manure was modelled using standard values (Ecoinvent, 2007; “Solid manure loading and spreading, by hydraulic loader and spreader”). The GWP was estimated to 3 g $CO_2$-eq/kg manure spread (Ecoinvent, 2007). Using the Danish national reference level for manure production for egg layers (Poulsen, 2011) and the egg production from the 5 production units, it was calculated that 4 g $CO_2$-eq/kg eggs was emitted when spreading manure. The GWP associated with spreading of 8.6 g artificial fertilizer N was considered to be zero.

Table 5 summarizes the GWP associated with the egg layer manure and the substituted usage of artificial fertilizer. The substituted 8.2 g N from ammonium nitrate fertilizer corresponds to 71 ***g*** $CO_2$-eq/kg eggs (see above). The methane emission from manure is estimated to contribute with 41 g $CO_2$-eq/kg eggs (1.64*25; see above) while the spreading of manure is estimated to contribute with 4 g $CO_2$-eq/kg eggs (see above). Therefore, the production of egg layer manure is estimated to contribute with a net GWP of 119 g $CO_2$-eq/kg eggs and the calculation is summed up in Table 5.

**Table 5.** Overview of the estimated GWP from egg layer manure and the corresponding substituted artificial fertilizer. The "difference" is the net GWP-contribution per kg eggs from manure production.

| | **Manure fertiliser ($g\ CO_2$-eq/kg eggs)** | **Artificial fertiliser ($g\ CO_2$-eq/kg eggs)** |
|---|---|---|
| $N_2O$ emission[1] | 195 | 50 |
| $CH_4$ emission | 41 | 0 |
| Production of N-fertiliser | 0 | 71 |
| Spreading manure | 4 | 0 |
| Total | 240 | 121 |
| Difference[2] | 119 | |

[1] calculated on the basis of the $N_20$ emission estimated in Table 3 and 4

[2] the difference is equal to GWP for manure (g $CO_2$-eq/kg eggs)

**By product: poultry waste**

WASTE FROM EGG PRODUCTION

Poultry waste includes dead hens form the egg production which are collected and transported to a destruction site (DAKA). It was assumed that 1 kg poultry waste processed at DAKA can 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 was 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 includes the processes of soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering are included. Inputs of fertilizers and seed as well as their transports to the farm are 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 DISCARDED EGG LAYERS

When the egg layers have produced eggs for app. 12 months they are discarded and transported to a factory specialised in processing them to mink feed (see inventory in Table 7). Therefore, the system was expanded to include production of fish meal and maize which is 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). This assumption was based on the facts that fish by-products are a suitable protein source for mink (Skrede, 2004), whereas soybean meal causes poor skin quality for the mink (Børsting, 2004), and that extruded maize has a high energy content for mink (Ahlstrøm et al., 2004).

From the content of crude protein and energy content in feedstuffs for mink (see Table 6), it was calculated that 229 g fish meal and 218 g maize corresponds to 1 kg poultry waste in terms of crude protein and energy that can be metabolized.

**Table 6.** Content of crude protein (CP) and energy that can be metabolized (ME) in feedstuffs 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)

The 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 includes the processes of soil cultivation, sowing, weed control, fertilization, pest and pathogen control, harvest and drying of the grains. Machine infrastructure and a shed for machine sheltering are included. Inputs of fertilizers and seed as well as their transports to the farm are 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).

The amount of poultry waste processed to mink feed was in average 91 g/kg eggs varying from 82 to 103 g/kg eggs for the 5 organic egg producers. Table 7 sums up the inventory for processing 1 kg poultry waste to mink feed and the GWP associated with the processing.

**Table 7.** Inventory for processing 1 kg poultry waste to mink feed and the estimated GWP for poultry waste.

| | |
|---|---|
| Transport poultry waste (kgkm/kg waste)[1] | 150 |
| Electricity (kWh/kg waste) | 0.034 |
| Gas (MJ/kg waste) | 0.603 |
| GWP processing waste (g *$CO_2$-eq/kg waste)* | 89 |
| GWP substituted feed (g *$CO_2$-eq/kg waste)*[2] | -291 |
| GWP (g *$CO_2$-eq/kg waste)* | -202 |
| GWP (g *$CO_2$-eq/kg eggs)*[3] | -18 |

[1] Assumed average distance from egg producers to the company that process poultry waste to mink feed (1 kg*150 km)
[2] Refers to the substituted fish meal and maize
[2] Average production of poultry waste from the 5 producers was 91 g/kg eggs

## LIFE CYCLE IMPACT ASSESSMENT AND INTERPRETATION

**Contributors to Global Warming Potential**
The GWP for 1 kg Danish organic eggs at the farm gate was estimated to 1.80 kg $CO_2$ eq., i.e. 112 g $CO_2$ eq per egg. The different contributors to the GWP are shown in Table 8. It was estimated that 85% of GWP arises from the egg production itself including GWP from exported manure and poultry waste, while 15% of GWP arises from the production of pullets.

**Table 8.** Contribution to the global warming potential (GWP) when producing 1 kg Danish organic eggs.

| | kg $CO_2$ eq/kg eggs | % of GWP |
|---|---|---|
| [1]Pullet production | 0.28 | 15 |
| [2]Egg production | 1.52 | 85 |
| Total | 1.80 | 100 |

[1] 0.059 pullets per kg eggs (See table 2)
[2]includes the by-products: egg layer manure which contributes with 0.119 kg $CO_2$ eq/kg egg and poultry waste which contributes with -0.018 kg $CO_2$ eq/kg eggs.

The different contributors to the GWP of the egg production itself, i.e. without pullet production, are shown in Table 9. Feed is by far the greatest contributor with 76% of the GWP. The 76% is a sum of total feed including: single concentrates (65%) being processed and pressed into pellets (10%) plus roughage in the form of silage (1%). Minor contributors are electricity (12%), manure (8%), diesel (2%) and other (2%).

**Table 9**. Contributors to the global warming potential of the egg production itself, i.e. excl. pullet production.

| | % of GWP |
|---|---|
| Concentrates | 65 |
| Feed manufacturing[1] | 10 |
| Roughage | 1 |
| Total feed | 76 |
| Electricity | 12 |
| Manure | 8 |
| Diesel | 2 |
| Other | 2 |

[1] processing and pressing different concentrates into pellets

The variation in GWP for pullet producers and egg producers is shown in Table 10. Two pullet producers participated in this investigation and therefore, the min and max value in Table 10 represent the GWP from each of these two rearing units. The variation between egg producers ranged from 1.34 to 1.86 kg $CO_2$ eq. per kg eggs.

**Table 10.** Variation in the global warming potential (GWP) for the 5 egg producers and the 2 rearing units.

| | kg $CO_2$ eq/kg eggs | min GWP | max GWP |
|---|---|---|---|
| Egg production units | 1.52 | 1.34 | 1.86 |
| Pullet production units | 0.28 | 0.23 | 0.32 |

The variation between egg producers is almost entirely due to differences in feed efficiency (kg feed/kg eggs). This is illustrated in Figure 2 where a relatively strong the relationship between feed efficiency and GWP is shown.

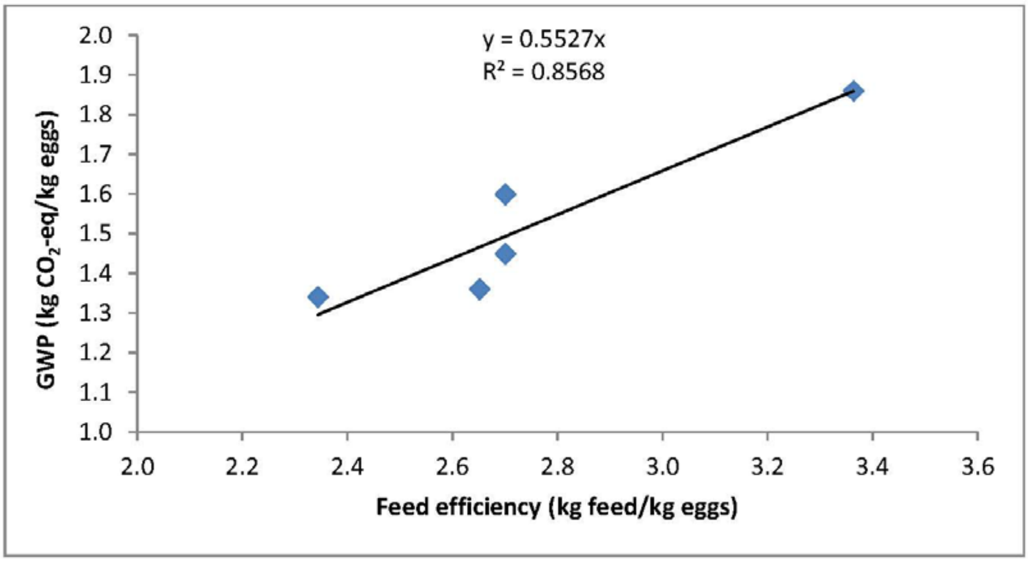


**Figure 2.** Relationship between feed efficiency and estimated GWP based on data collection from 5 Danish organic egg producers.

**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 has been subject for sensitivity analysis. In the following, the consequential approach for calculating GWP from feed has also been investigated.

IMPACT OF GWP FOR ORGANIC WHEAT

Wheat is the quantitatively most important feedstuff for egg production making up 42% of the feed ration (see Table 2). The wheat used in this report had an estimated GWP of 322 g $CO_2$-eq/kg based on Danish data (Mogensen et al., 2011), but if Swiss organic wheat with a GWP of 595 g $CO_2$-eq/kg (Ecoinvent, 2007) was used instead, the GWP for 1 kg eggs would increase from 1.80 to 2.12 kg $CO_2$-eq/kg eggs, i.e. an increase of 18%. The lower GWP for Danish organic wheat is not likely to be due to differences in yield, which were quite similar (DK: 3600 kg/h; CH: 4069 kg/ha) (Ecoinvent, 2007). The big difference in GWP for wheat in the Danish and the Swiss investigation is therefore likely to be related to the amount of fertilizer used and differences in IPCC emissions factors for laughing gas.

IMPACT OF GWP FOR ORGANIC SOYBEAN CAKE

Soybean cake is the most used protein source for organic egg layers making up 8% of the feed ration (see Table 2). Including other protein sources such as sunflower cake and fishmeal, which also were modelled as soybean cake (see *Feed section*), 15% of the ration can be considered as being soybean cake. The organic soybean cake used in this investigation had an estimated GWP of 357 g $CO_2$-eq/kg based on Chinese soybean data from Knudsen et al. (2010). However, if organic soybean meal based on soybean production in South America with a GWP of 720 g $CO_2$-eq/kg from Mogensen et al. (2011) was used instead, the GWP for 1 kg eggs would increase from 1.80 to 1.95 kg $CO_2$-eq/kg eggs, i.e. an increase of 8%. The higher GWP for soybean meal estimated by Mogensen et al. (2011) is due to higher GHG emission from both the growing and the transportation of soybeans compared to Knudsen et al. (2010).

IMPACT OF GWP FOR ARTIFICIAL FERTILIZER

The artificial fertilizer, which is saved due to the production of egg layer manure, used in this investigation has a GWP of 8.7 kg $CO_2$-eq/kg N. However, modern production of fertilizer has been claimed to have a GWP 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). Using a value of 4.0 kg $CO_2$-eq/kg N, the GWP for production of N-fertilizer would decrease from 71 (see Table 5) to 33 g $CO_2$-eq/kg eggs, i.e. a reduction of 38 g $CO_2$-eq. Thus, using 4.0 kg $CO_2$-eq/kg N, would increase the GWP for 1 kg eggs from 1.80 to 1.838 kg $CO_2$-eq, corresponding to 2.1%.

IMPACT OF INCLUDING SAVED ARTIFICIAL P AND K FERTILIZER

One could argue that also P and K would be saved when egg layer manure is produced. Therefore, a scenario was modelled where artificial N, P and K fertilizer was saved due to the production of egg layer manure. GWP values for the production of P and K fertilizer was taken from LCA Food DK (2006), which amounts to 2.69 and 0.80 kg $CO_2$-eq/kg P and K, respectively. From the amount of P and K in egg layer manure (Poulsen, 2011), it was calculated that 3.95 g P and 5.27 g K was produced per kg eggs. When P and K were included in the LCA, the GWP for 1 kg eggs decreased with 14 g $CO_2$-eq, i.e. a reduction of 0.8%.

IMPACT OF ALTERNATIVE CONSEQUENTIAL APPROACH FOR CALCULATING GWP FROM FEED

The consequential approach has been to model all feed components as soybean meal and barley with respect to the content of protein and energy in the feed ration, i.e. converting all feedstuffs to a mixture of soybean meal and barley (Dalgaard et al., 2007; Nguyen et al., 2011). If this approach was used and organic wheat (322 g $CO_2$-eq/kg) and organic soybean cake (357 g $CO_2$-eq/kg) was assumed the marginal energy and protein source, respectively, it would require 1.829 kg wheat and 0.751 kg soybean meal. The GWP was then estimated to decrease from 1.52 to 1.39 kg $CO_2$-eq/kg eggs at egg producer level, corresponding to 9%.

**Results from other investigations**

Few approaches have been made to estimate GWP for organic eggs and there are a limited number of LCA's in the literature. The results in table 11 are not directly comparable due to different production systems (conventional, free range or organic), different LCA methods and different boundaries in the studies. But table 11 serves the purpose of showing that the results obtained in this report (Nielsen et al., 2013) seems reasonable.

**Table 11.** Global warming potential (GWP) of egg production at the farm gate. Note that different production systems, LCA-methods and system boundaries have been used in the different studies.

| Reference | Kg $CO_2$-eq per kg eggs |
|---|---|
| LCA Food (2006)[1] | 2.0 |
| Carlsson et al. (2009) [2] | 1.4 |
| Baumgartner et al. (2008) [1] | 2.7 |
| Wiedemann et al. (2011)[1] | 1.3 |
| Wiedemann et al. (2011)[3] | 1.6 |
| Williams et al. (2009)[1] | 1.5 |
| Williams et al. (2009)[3] | 1.7 |
| Williams et al. (2009)[2] | 1.8 |

[1] conventional/caged production
[2] organic production
[3] free range production

### Conclusion

The GWP of 1 kg eggs at the farm gate was estimated to 1.80 kg $CO_2$ eq, i.e. 112 g $CO_2$ eq per egg. The production of pullets contributed with 15% of GWP while the production of eggs contributed with 85%. At egg producer level the major contributor to GWP is feed with 76%. Minor contributors are electricity (12%), manure (8%), diesel (2%) and other (2%).

Sensitivity calculations have shown that the GWP of organic eggs is sensitive to the GWP-data used for wheat and soybean cake.

The variation in feed efficiency between Danish organic egg producers suggests that the biggest potential for reducing GWP in the short term is to improve feed efficiency.

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# APPENDIX

**Final Review Statement** **12th April 2012**

**Greenhouse gas Emission from Danish Organic Egg production estimated via LCA Methodology**

We have read the report carefully. It seems to be a sound assessment and the chosen LCA methodology is appropriate for addressing the subject in question: global warming potential of organic egg produced at Danish farms, and to identify the hot spots of the products/processes with major contributions to the GWP of Danish organic eggs.

In general, the report is very well written and easy to read.

We had some specific comments and suggestions for improvement. The authors have been able to follow these suggestions.

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