Environmental footprint of Danish egg production systems in 2000 and 2020

CONFIDENTIAL – report for Danish Egg Association

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blonk consultants

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Date	20-10-2021	
Place	Gouda, NL	
Authors	Freija van Holsteijn	Blonk Consultants
	Simone Hesseling	Blonk Consultants
	Jasper Scholten	Blonk Consultants
	…	…

Blonk Consultants
Groen van Prinsterersingel 45
2805 TD Gouda

+31(0)182 579970
www.blonkconsultants.nl
info@blonkconsultants.nl

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1. Introduction

The project entails a screening life cycle assessment (LCA) of four different egg production systems in Denmark. The environmental impact of Danish egg production in the year 2020 is benchmarked to the year 2000. The project was commissioned by Danish Egg Association (Danske Æg) and executed by Blonk Consultants.

The study is based on primary egg production data delivered by Danish Egg Association, which covers data for cage, barn, free-range and organic housing systems. In addition, the study relies on background data from the Agri-footprint 5.0 database.

This report elaborates on the life cycle assessment (LCA) methodology, defines the goal and scope, describes the approach, includes the life cycle inventory (LCI), shows results and interprets the results.

2. LCA Methodology

Life Cycle Assessment (LCA) is a method to evaluate and quantify the environmental impact of a product or service. LCA captures the whole supply chain (from cradle to grave) with its individual stages. Included are raw-material production, production, distribution, transportation, use and disposal of a specific product (or service). By integrating all life cycle stages, life cycle assessment provides a holistic approach, allowing to observe interactions between stages. This can facilitate the identification of opportunities for indirect environmental management along the whole chain, or to observe potential "burden shifting" when comparing alternative systems.

The goal of an LCA is to get insight in the environmental impacts of a product or service, by quantifying all inputs and outputs of material flows. The results of an LCA can be applied for product development, strategic planning, marketing and communication towards customers.

Blonk Consultants performed a screening LCA in accordance with the international standards ISO 14040 and ISO 14044 (ISO, 2006a, 2006b) and where relevant followed the guidelines of the Product Environmental Footprint of the European Union (PEF) (European Commission, 2018b). In addition, the Livestock Environmental Assessment and Performance Partnership (LEAP) guidelines are used for guidance on animal feed, poultry supply chains and nutrient flows. The International Panel of Climate Change (IPCC) guidelines are used for the calculation of nitrogen and methane emissions from egg production. The LCA is modelled in LCA-software SimaPro and available for future use.

This LCA is conducted according to the iterative multi-step, methodology proposed in ISO 14040 (ISO, 2006a).

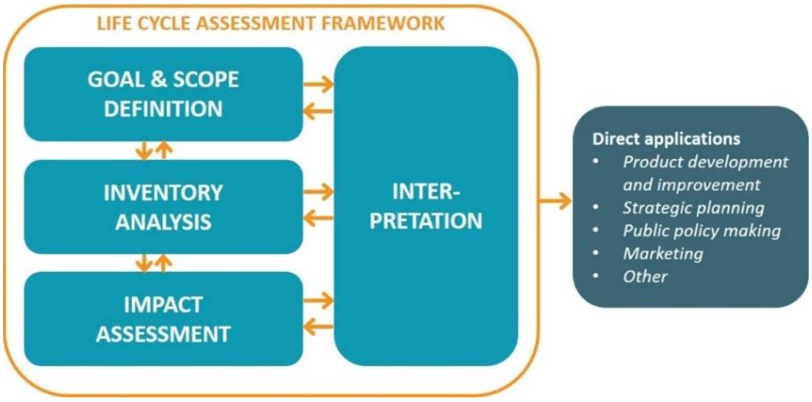

Figure 1 Methodological steps in LCA based on ISO 14040.

- **Goal and scope**: this step provides a description of the product system in terms of system boundaries and functional unit.
- **Inventory analysis**: also called life cycle inventory (LCI) is a methodology for estimating the consumption of resources and the quantities of waste flows and emissions caused by or otherwise attributable to a product's life cycle.
- **Impact assessment**: also known as life cycle impact assessment (LCIA) provides indicators and the basis for analysing the potential contributions of the resource extraction and emissions in an inventory to a number of potential impacts.
- **Interpretation**: in this phase the results of the analysis and all choices and assumptions made during the analysis are evaluated in terms of soundness and robustness. After this, overall conclusions are drawn.

3. Goal and scope

3.1 Goal

The overall goal of this project is to assess the environmental impact of cage, barn, free-range and organic egg production systems in 2000 and 2020 in Denmark. The functional unit is 1 kg eggs.

3.2 System boundaries

The system boundaries are from cradle-to-farm-gate. The so-called "cradle" is representative for the crop cultivation and related upstream processes (e.g. fertilizer, raw materials, and energy production), and at the farm gate the eggs leave the laying hen farm (Figure 2).

The foreground systems are the animal production systems. This means that primary data was collected for these systems. Included foreground systems are pullet rearing and egg production by laying hens. The cultivation, processing of feed ingredients, compound feed production and transport life cycle phases are considered background systems. Blonk Consultant creates and owns datasets that cover background systems (Agri-footprint 5.0). Moreover, Blonk Consultants used own tools to create additional datasets (e.g. for organic feed ingredients and datasets based on 2000 data).

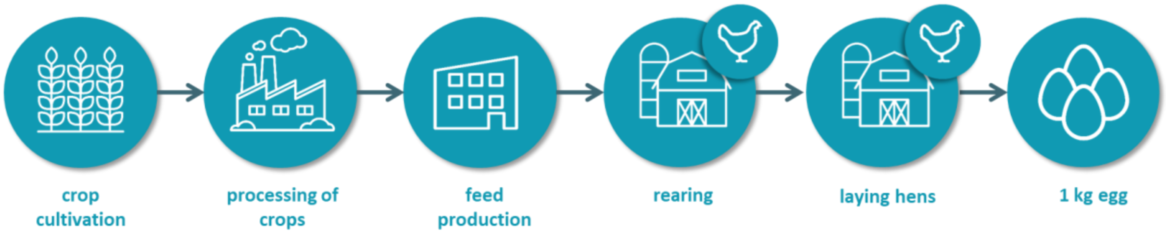

Figure 2 Schematic illustration of cradle-to-farm gate system boundaries and functional unit of 1 kg egg.

3.3 Impact categories

Environmental impact categories relevant for this study are listed in Table 1, together with a description of each impact category.

Table 1 Environmental impact categories analysed in this study.

Impact category	Description
Global Warming (kg CO_2 equivalents)	The *ReCiPe* method is to be used for calculating global warming potential of the evaluated systems (Huijbregts et al., 2016). Global warming means a global increase in temperature. This might be caused by various factors, such as biotic processes, but it is particularly induced by human activities, such as the

	combustion of fossil fuels and deforestation. These processes result in higher concentration of greenhouse gases (GHG's) in the atmosphere, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The warming potential of greenhouse gases is expressed in reference to CO_2 and their aggregated impact is expressed in kg CO_2 equivalents. The CO_2 equivalents of one kilogram CH_4 and N_2O are 34 and 298 kg CO_2, respectively. The total amount of kg CO_2 eq. is also referred to as "carbon footprint". Special attention is given to Global Warming because this impact category is high on sustainability agendas worldwide.
Land use change (LUC) (inducing global warming) (kg CO_2 equivalents)	Land use change is the change in the purpose for which land is used by humans (e.g. between crop land, grass land, forest land, wetland, industrial land). Land use change has a direct impact to climate change when the transformation of land reduces carbon stocks and/or generates greenhouse gas emissions during removal. Land use change in LCA is considered when having occurred during the last 20 years. The impact of land use change is calculated in kg CO_2 equivalents and is part of the total global warming impact, yet always reported separately. The PAS 2050-1 method is applied and LUC emission factors are calculated using the LUC impact-tool (Blonk Consultants, 2018; BSI, 2012).
Water scarcity (m^3 world equivalent)	The AWARE method is used for calculating the water use of the evaluated systems. Water use in AWARE represents the relative Available WAter REmaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived. The method defines water scarcity factors per national and sub-national regions in relation to the world's equivalent water use. Regions of low water availability are assigned a higher scarcity factor.
Land use / occupation	Occupation refers to the use of a land cover for a certain period, and it is measured as area-time (m^2a)
Eutrophication	Covers the impacts on aquatic environments due to over-fertilisation or excess supply of nutrients, particularly focusing on the most important substances nitrogen (N) and phosphorus (P).
Respiratory inorganics / particulate matter	Indicator of the potential incidence of disease due to particulate matter emissions. PM10 refers to particles with an aerodynamic diameter smaller than 10 µm, and PM2.5 refers to particles with an aerodynamic diameter smaller than 2.5 µm. The EEA/EMEP emission calculation guidelines 2019 were used to calculate PM emissions on-farm (European Environment Agency, 2019)

3.4 General information on impact allocation

When conducting a life cycle assessment, the overall goal is to map the processes and products in scope as detailed as possible, simulating reality, in order to get a representative system and impact. If a production system cannot be subdivided any further into different smaller stages, and a process results into more than one product output, life cycle impact should be attributed to these co-products.

In this case, the approach for attributing life cycle impact between co-products is called 'allocation'. The most relevant relationship between the co-products determines how impact is allocated. Such a relationship relates to a (bio-)physical or economic interdependency.

There are several ways to allocate the impact of a process to the different (co-)products. In general, allocation standards as proposed by the general PEFCR Guidance (European Commission, 2018a) and LEAP guidelines (LEAP, 2015) are used.

3.4.1 Allocation rules applied in this study

The current study follows general and specific PEFCR and LEAP guidelines to determine allocation factors for partitioning the environmental impact of multi-output systems to the different outputs.

Biophysical allocation is applied for attribution of impact at the point of egg production, following the LEAP guidelines. This biophysical allocation is based on the proportion of total energy requirements (metabolized energy) for egg production and weight gain of the laying hen. The metabolized energy (ME) value for layer weight gain is 3.36 kcal ME/day per/day of weight gain. For egg production this is 2.21 kcal ME/day per g/day egg mass (FAO, 2019). Since every laying system (cage, barn, free-range and organic) has a specific output mass of eggs and spent hens, biophysical allocation percentages will differ slightly among the different laying systems. Biophysical allocation percentages are shown in Table 2. As the overview points out, allocation percentages are comparable.

For the attribution of impact of feed crops at the crop cultivation level, economic allocation is used. This follows from the Agri-footprint 5.0 methodology (Van Paassen et al., 2019a), which is based on the PEFCR guidelines. Economic allocation is a method to allocate impact based on the way co-products create economic value for their producer. More impact is allocated to co-products that cover a larger share of the revenue.

Table 2 Biophysical allocation at layer hen farm

Egg production system	Biophysical allocation % to eggs	Biophysical allocation % to spent hens
Cage eggs (2000)	97,5%	2,5%
Cage eggs (2020)	97,9%	2,1%
Barn eggs (2000)	98,4%	1,6%
Barn eggs (2020)	97,9%	2,1%
Free-range eggs (2000)	98,3%	1,7%
Free-range eggs (2020)	97,8%	2,2%
Organic eggs (2000)	98,2%	1,8%
Organic eggs (2020)	97,6%	2,4%

4. Approach

4.1 Description of egg production systems

In this chapter, the four egg production systems considered are described more elaborately. General differences between 2000 and 2020 are that 1) a switch has been made from floor systems to aviary systems (for free-range, barn and organic eggs); 2) manure is removed more often during the production period; 3) compound feed content has been changed, and more often, layers are fed with whole wheat grown on-farm; 4) transport distances have decreased; 5) laying hen production period is extended. Table 3 provides a more detailed overview.

Table 3 description of egg production systems

Egg production system	Description
Cage eggs (2000)	One-day-chicks are transported for 250 km to pullet rearing facilities. Pullets are kept in cages for a production period of 119 days. Amount of animal places per year is 1,415,562. Manure is removed once a week. Manure management system is a solid storage without litter. Pullets are fed with compound feed. Pullet rearing facilities are heated using oil as a source of energy.

	Pullets are transported for 125 km to layer hen facilities. Layers are kept in cages for a production period of 392 days. Laying hens are fed with compound feed as well as whole wheat. The manure management system exists for 90% of solid storage without litter.
Cage eggs (2020)	Transport distance of one-day-chicks to pullet rearing facilities is 200 km Pullets are kept in cages for a production period of 119 days. Amount of animal places per year is 492,667. Manure is removed twice a week. Manure management system is a solid storage without litter. Pullets are fed with compound feed. Pullet rearing facilities are heated using oil as a source of energy. Pullets are transported for 70 km to layer hen facilities. Layers are kept in cages for a production period of 457 days. Layers are fed with compound feed. The manure management system exists for 28% of solid storage without litter.
Barn eggs (2000)	One-day-chicks are transported for 250 km to pullet rearing facilities. Pullets are raised on floor systems for a production period of 119 days. Amount of animal places per year is 462,993. All manure stays in the house until the pullets are transported to the next stage. Manure management system is a 100% solid storage with litter. Pullets are fed with compound feed. Straw and wood shavings are used as bedding material. Pullet rearing facilities are heated using oil as a source of energy. Pullets are transported for 125 km to layer hen facilities. Layers are kept on floor systems for a production period of 364 days. Laying hens are fed with compound feed. The manure management system exists for 100% of solid storage with litter.
Barn eggs (2020)	One-day-chicks are transported for 200 km to pullet rearing facilities. Pullets are raised on aviary systems for a production period of 119 days. Amount of animal places per year is 1,446,741. Pullets are fed with compound feed. Straw and wood shavings are used as bedding material. 80% of manure stays in the house until the pullets are ready for the next stage. 20% of manure is removed during pullet rearing period. Manure management system is a 50% solid storage system with litter. The other 50% is an aerobic digestion system. Pullet rearing facilities are heated using oil as a source of energy. Pullets are transported for 70 km to layer hen facilities. Layers are kept on aviary systems for a production period of 437 days. Laying hens are fed with compound feed and whole wheat grown on farm. Manure is removed 2 to 3 times a week. The manure management system exists for 30% of solid storage with litter.
Free-range eggs (2000)	One-day-chicks are transported for 250 km to pullet rearing facilities. Pullets are raised on floor systems for a production period of 119 days. Average amount of animal places per year is 256,852. All manure stays in the house until the pullets are transported to the next stage. Manure management system is a 100% solid storage with litter. Pullets are fed with compound feed. Straw and wood shavings are used as bedding material. Pullet rearing facilities are heated using oil as a source of energy. Pullets are transported for 125 km to layer hen facilities. Layers are kept on floor systems for a production period of 336 days. Laying hens are fed with compound feed. Manure is removed if production stage is finished. The manure management system exists for 100% of solid storage with litter.
Free-range eggs (2020)	One-day-chicks are transported for 200 km to pullet rearing facilities. Pullets are raised on floor systems for a production period of 119 days. Average amount of animal places per year is 288,811. 80% of manure stays in the house until the pullets are ready for the next stage. 20% of manure is removed twice a week during pullet rearing period. Manure management system consists for 80% of solid storage with litter. Pullets are fed with compound feed. Straw and wood shavings are used as bedding material. Pullet rearing facilities are heated using oil as a source of energy.

	Pullets are transported for 70 km to layer hen facilities. Layers are kept in aviary systems for a production period of 404 days. Laying hens are fed with compound feed and whole wheat grain grown on farm. Manure is removed twice a week. The manure management system exists for 60% of solid storage with litter.
Organic eggs (2000)	One-day-chicks are transported for 250 km to pullet rearing facilities. Pullets are raised on floor systems for a production period of 119 days. Average amount of animal places per year is 391,071. All manure stays in the house until the pullets are transported to the next stage. Manure management system is a 100% solid storage with litter. Pullets are fed with compound feed. Straw and wood shavings are used as bedding material. Pullet rearing facilities are heated using oil as a source of energy. Pullets are transported for 125 km to layer hen facilities. Layers are kept on floor systems for a production period of 336 days. Laying hens are fed with compound feed. Manure is removed if production stage is finished. The manure management system exists for 100% of solid storage with litter.
Organic eggs (2020)	One-day-chicks are transported for 200 km to pullet rearing facilities. Pullets are raised on aviary systems for a production period of 119 days. Average amount of animal places per year is 1,088,379. Pullets are fed with compound feed, and they spend 55% of their time outside. 10% of producers remove manure 2 to 3 times a week. Manure management system consists for 50% of solid storage with litter. Straw and wood shavings are used as bedding material. Pullet rearing facilities are heated using oil as a source of energy. Pullets are transported for 70 km to layer hen facilities. Layers are kept in aviary systems for a production period of 410 days. Laying hens are fed with compound feed, whole wheat grain and roughages grown on farm. Manure is removed twice a week. The manure management system exists for 30% of solid storage with litter.

A schematic overview of the housing systems and years is provided in Figure 3. A schematic overview of different in- and outputs related to a specific housing system is presented in Figure 4.

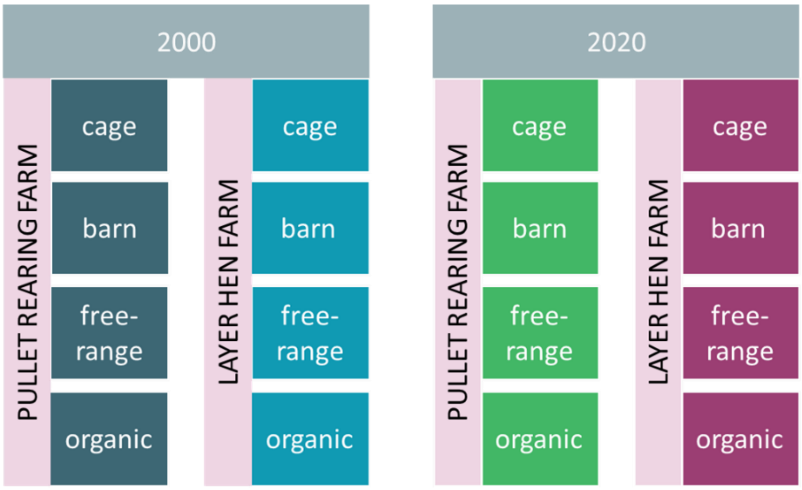

Figure 3 overview of housing systems and year

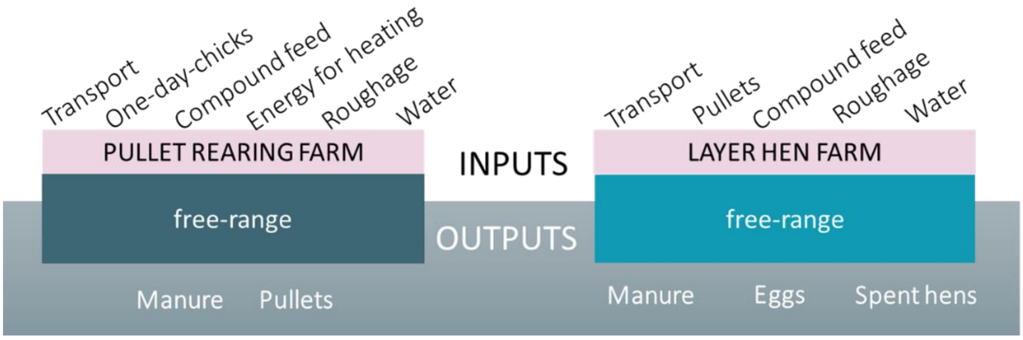

Figure 4 schematic overview of the main in- and outputs for a housing system

4.2 Modelling approach

A stepwise approach was formulated to model the egg production systems in LCA software.

- Step 1: Feed ingredients
- Step 2: Pullet rearing
- Step 3: Egg production (layer farms)

Step 1 included the modelling of all feed ingredients used in historical (year 2000) and organic systems (years 2000 and 2020). Feed is the main environmental impact hot spot for egg production, so the data quality of the feed datasets is crucial in this study. This includes the cultivation phase of each crop, processing of crops into feed material, and transport of feed material to Denmark. Since not all feed ingredients are available in the Agri-footprint 5.0 database, they were modelled.

Step 2 included modelling of pullet compound feed production, and pullet rearing including on-farm emissions. Step 3 included modelling of layer compound feed production, and egg production including on-farm emissions.

Chapter 5 discusses the data used and assumptions made.

5. Life Cycle Inventory

5.1 Primary and secondary data

This chapter provides an overview of the life cycle inventory (LCI), which encompasses data collection in this study. A distinction is made between primary and secondary data, with the former referring to activity data collected by Danish Egg Association and the later referring to generic data based on statistics or empirical models.

‘Primary data’ (else called company-specific data) refers to directly measured or collected data from facilities (site-specific data) operated by the organisation that performs the study or that the organisation has access to.

‘Secondary data’ refers to data not from specific processes available to the organisation, but rather more generic processes. Secondary data sources are used for modelling the crop cultivation, crop processing, and supplementing transport data. Two main sources for secondary data are LCA databases Agri-Footprint 5.0 and Ecoinvent 3.6.

Figure 5 illustrates what part of the life cycle is based on secondary data (in blue) and on primary data (in orange). At feed production, primary data was used for the feed composition of both pullet and layer compound feeds, default data was used for energy requirements and transport to the feed mill.

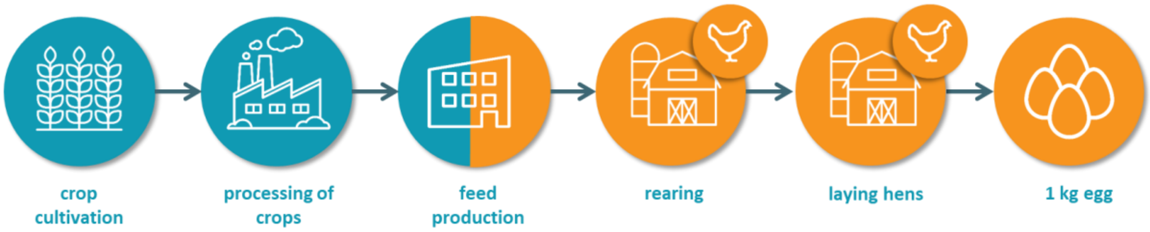

Figure 5 Schematic illustration of the use of primary and secondary data per life cycle stage. Orange = primary, Blue = secondary.

5.2 Step 1: feed ingredients

Methodological and life cycle inventory complexities are mainly related to feed. In step 1 the goal was to model the feed ingredients not available in Agri-Footprint 5.0. These include the historic feeds from conventional and organic cultivation, and the 2020 organic feeds. All crops were modelled following the approach of Agri-Footprint as much as possible, to keep consistent with the crops already available in Agri-Footprint (Van Paassen et al., 2019b).

Yield per hectare is one of the most important parameters of crop cultivation LCA's. Crop LCA's currently in Agri-Footprint are based on a 5-year yield average (2012-2016) from FAO statistics. Similarly, the historic crops modelled for this study are based on a 5-year average from 1998-2002 (see Table 4). Yields of organic crops is a known data gap for which no statistical data is available. Blonk has approached several European organisations for organic agriculture (FiBL, IFOAM) who confirmed this. As an alternative approach, organic yields were estimated based on the yield of conventional crops multiplied by yield gap factor reported by De Ponti et al. (2012), shown in Table 5. For example, conventional wheat cultivated in 2000 had an average yield of 7225 kg per hectare. According to De Ponti et al. (2012), the yield gap between organic and conventional wheat is 0.73, making the organic yield 5274 kg/ha.

Table 4 List of crop-country combinations modelled for this LCA.

Crop	Country	Year	Org/Conv	Yield (kg/ha)	Source
Maize	France	2000	Conventional	*8806*	*FAOstat crop yield 1998-2002*
Wheat	Denmark	2000	Conventional	*7225*	*FAOstat crop yield 1998-2002*
Soybeans	Argentina	2000	Conventional	*2537*	*FAOstat crop yield 1998-2002*
Sunflower seed	Ukraine[1]	2000	Conventional	*1058*	*FAOstat crop yield 1998-2002*
Oil palm fruit	Malaysia	2000	Conventional	*16135*	*FAOstat crop yield 1998-2002*
Oats	Denmark	2000	Conventional	*5044*	*FAOstat crop yield 1998-2002*
Barley	Denmark	2000	Organic	3580	*FAOstat crop yield 1998-2002 multiplied by yield gap*
Oats	Denmark	2000	Organic	4287	*FAOstat crop yield 1998-2002 multiplied by yield gap*
Wheat	Denmark	2000	Organic	5274	*FAOstat crop yield 1998-2002 multiplied by yield gap*
Peas, dry	Denmark	2000	Organic	2987	*FAOstat crop yield 1998-2002 multiplied by yield gap*
Rapeseed	Denmark	2000	Organic	2296	*FAOstat crop yield 1998-2002 multiplied by yield gap*
Grass	Denmark	2000	Organic	76875	*Internal communication L. Holdensen, 2021.*
Maize	France	2000	Organic	7837	*FAOstat crop yield 1998-2002 multiplied by yield gap*
Soybeans	China	2000	Organic	1609	*FAOstat crop yield 1998-2002 multiplied by yield gap*
Sunflower seed	Ukraine[1]	2000	Organic	815	*FAOstat crop yield 1998-2002 multiplied by yield gap*

Rapeseed	Ukraine[1]	2020	Organic	2011	*FAOstat crop yield 2012-2016 multiplied by yield gap*
Maize	Ukraine[1]	2020	Organic	5283	*FAOstat crop yield 2012-2016 multiplied by yield gap*
Soybeans	China	2020	Organic	1652	*FAOstat crop yield 2012-2016 multiplied by yield gap*
Wheat	Ukraine[1]	2020	Organic	2670	*FAOstat crop yield 2012-2016 multiplied by yield gap*
Sunflower seed	Argentina	2020	Organic	1494	*FAOstat crop yield 2012-2016 multiplied by yield gap*
Maize	Denmark	2020	Organic	5845	*FAOstat crop yield 2012-2016 multiplied by yield gap*
Barley	Denmark	2020	Organic	3989	*FAOstat crop yield 2012-2016 multiplied by yield gap (4 ton/ha L. Holdensen)*
Oats	Denmark	2020	Organic	4300	*FAOstat crop yield 2012-2016 multiplied by yield gap (4 ton/ha L. Holdensen)*
wheat	Denmark	2020	Organic	5491	*FAOstat crop yield 2012-2016 multiplied by yield gap (5 ton/ha L. Holdensen)*
Peas, dry	Denmark	2020	Organic	3330	*FAOstat crop yield 2012-2016 multiplied by yield gap (4 ton/ha L. Holdensen)*
Rapeseed	Denmark	2020	Organic	3162	*FAOstat crop yield 2012-2016 multiplied by yield gap (3 ton/ha L. Holdensen)*
Grass	Denmark	2020	Organic	76875	*Internal communication L. Holdensen, 2021.*
Maize	France	2020	Organic	7796	*FAOstat crop yield 2012-2016 multiplied by yield gap*
Sunflower seed	Ukraine[1]	2020	Organic	1566	*FAOstat crop yield 2012-2016 multiplied by yield gap*

[1] Ukraine as country of cultivation for crops sources from Eastern Europe was assumed

Table 5 Average yield gap between organic and conventional crop cultivation (De Ponti et al., 2012).

Crop	**Yield gap for organic crops**
Maize	0.89
Soybeans	0.92
Wheat	0.73
Peas, dry	0.85
Barley	0.69
Oats	0.85
Sunflower seed	0.77
Rapeseed	0.82

Besides crop yield data, information on the quantities and types of fertilizer used in organic cultivation is also lacking. Therefore, a simplified method was chosen, assuming that animal manure was the only fertilizer applied to organic crops. The amount of animal manure applied was based on the total nitrogen applied in conventional crop farming and corrected for crop output. Nitrogen applied per hectare in organic crop production was estimated as:

$$\frac{\left[\dfrac{\text{Artificial fertilizer in conv. crop production (kg N/ha)}}{\text{N fertilizer replacement value (NFRV) (\%)}} + \text{Animal manure in conv. crop production (kg N/ha)}\right]}{\text{Conventional crop yield (kg/ha)}} \times \text{Organic crop yield (kg/ha)}$$

Fertilizer quantities (both artificial and animal manure) of conventional crop production were based on data in Agri-Footprint. The NFRV is the percentage of N in animal manure that is available for the crop. By multiplying the NFRV with the N content of animal manure, the quantity of N was calculated replacing N from artificial fertilizer. It was assumed that animal manure consisted of solid and slurry from cattle, pig slurry, and poultry manure. Based on long term effectiveness per kg N per type of animal manure, the average NFRV was 73%, or in other words 1 kg N of animal manure is equivalent to 0.73 kg N from artificial fertilizer.

Table 6 Ratios of nitrogen from animal manure applied per hectare, nitrogen fertilizer replacement value (NRFV) per type of animal manure and nitrogen available to the crop.

	N manure/ha	NFRV [1]	N supply/ha
Slurry cattle	0.25	75%	0.19
Solid cattle	0.25	55%	0.14
Pig slurry	0.25	85%	0.21
poultry	0.25	75%	0.19
Total	1.00		0.73

[1] (Schroder & van Dijk, 2019)

5.3 Step 2: pullet rearing

Total inputs and outputs per pullet rearing system are described, as well as the on-farm emission calculations.

The composition of pullet compound feeds for cage, barn and free-range systems are the same. Therefore, one conventional compound feed for 2000 and one conventional compound feed for 2020 was modelled (see appendix I). A separate compound feed was modelled for organic pullets for 2000 and 2020.

5.3.1 Total inputs and outputs per pullet housing system

In this section, the total in and outputs per pullet housing system are described. The year 2000 is used as baseline to which increased or decreased in and output values for the year 2020 were benchmarked.

- In general, for all pullet production systems, feed compositions have changed. The feed conversion ratio for all systems has increased, except for the free-range 2020 production system,
  - Regarding the **cage** production system, the feed intake per day has slightly decreased, as well as the end weight of pullets. Less electric energy was consumed in 2020, whereas more oil was used for heating.
  - Regarding the **barn** production system, the feed intake has slightly decreased, and the start weight of chicks as well as the end weight of pullets has decreased. The flock mortality rate has decreased. Less electric energy was consumed, but more oil was used for heating.
  - The **free-range** production system has a decreased feed conversion ratio. The start weight of chicks in 2020 is lower than in 2000, the total feed intake has decreased and the pullet end weight has also decreased. In addition, the flock mortality rate has decreased. Similar to the other production systems, electricity consumption has decreased, whereas oil consumption for heating increased.
  - For the **organic** production system, the start weight of chicks and the end weight of pullets have decreased from 2000 to 2020. The flock mortality rate has decreased. Electricity consumption, as well as oil consumption for heating have decreased.

Table 7 Pullet rearing characteristics per housing system per year.

	Cage		Barn		Free-range		Organic	
	2000	2020	2000	2020	2000	2020	2000	2020
FCR (kg feed/kg weight gain)	4.79	4.77	4.58	4.77	4.42	4.24	5.34	5.80
Feed intake (kg/head/day)	0.049	0.048	0.051	0.047	0.051	0.047	0.061	0.058
o/w compound feed incl. concentrates	100%	100%	100%	100%	100%	100%	100%	100%
o/w wheat own farm	0%	0%	0%	0%	0%	0%	0%	0%

o/w roughages	0%	0%	0%	0%	0%	0%	0%	0%
Start weight (gram/chick)	42	42	42.6	42	42.6	42	42.6	42
End weight (kg/pullet)	1.27	1.25	1.45	1.25	1.45	1.25	1.45	1.25
Flock mortality	3%	3%	5.5%	3.5%	5.5%	3.5%	5.5%	3.5%
Production cycle (days)	119	119	119	119	119	119	119	119
Electricity (kWh/pullet	0.60	0.51	0.15	0.11	0.64	0.5	0.67	0.55
Oil for heating (l/pullet	0.10	0.11	0.30	0.026	0.30	0.12	0.30	0.12
Outdoor area (m2/bird)	0	0	0	0	0	0	0	1

5.3.2 Total calculated nitrogen and methane emissions pullets

Nitrogen emission calculations were based on nitrogen taken in by pullets through feed, nitrogen retention in the body and nitrogen excretion through manure. Input data for calculations (nitrogen-intake) was based on the nitrogen composition of the feed and the total feed intake. Calculations for nitrogen excretion, retention, and emissions were based on IPCC guidelines (Dong, Mangino & Jerry, 2019). Calculated nitrogen emissions include direct and indirect N2O emissions, NH3 emissions, NO emissions, and N2 emissions.

Methane emission calculations for poultry manure management were based on LEAP guidelines (LEAP, 2015)

- For digestibility a LEAP default of 80% was used.
- For the ash content of the manure a LEAP default of 10% was used.
- For the methane conversion factor, a default was taken from IPCC guidelines.

5.4 Step 3: egg production

Total inputs and outputs per layer housing system are described, as well as the on-farm emission calculations.

The composition of layer compound feeds for cage, barn and free-range systems are the same. Therefore, one conventional compound feed for 2000 and one conventional compound feed for 2020 was modelled (see appendix I). A separate compound feed was modelled for organic layers for 2000 and 2020.

5.4.1 total inputs and outputs per layer housing system

In this section, the total in and outputs per layer housing system are described. The year 2000 is used as baseline to which increased or decreased in and output values for the year 2020 were benchmarked.

- In general, 1) for all layer production systems, feed compositions have changed; 2) For all production systems in the period 2000-2020, the feed conversion ratio has decreased; and 3) for all layer production systems have added 15-22% of days to the production cycle.
  - Regarding the **cage** production system, the feed intake per day has slightly increased. The net weight gain from pullet to spent hens has stayed the same. The flock mortality rate has decreased. Less electricity was consumed in 2020.
  - Comparing the **barn** production systems from 2000 to 2020, the feed intake has slightly decreased, whereas the net weight gain has increased. The flock mortality rate has decreased. Less electricity was consumed.
  - Next to the change in compound feed composition, layers in the **free-range** production system of 2020 were fed wheat grain grown on the farm as 24% of their diet. The start weight of pullets in 2020 is lower than in 2000, the feed intake has slightly decreased, whereas the net weight gain has increased. However, the flock mortality rate has decreased. Similar to the other production systems, electricity consumption has decreased.
  - For the **organic** production system, the start weight of pullets in 2020 is lower than in 2000, the feed intake has decreased, whereas the net weight gain has increased. From the original diet of compound feed, 9.2% was replaced by wheat grown on the farm, and 7.9% was replaced by roughages. The type of roughage was unspecified in the primary data, therefore a 50/50 mixture of

grass meal and lucerne was assumed. In addition, the flock mortality rate has greatly decreased. Electricity consumption has decreased too.

Table 8 Layer production characteristics per housing system per year.

	Cage		Barn		Free-range		Organic	
	2000	2020	2000	2020	2000	2020	2000	2020
Average number of eggs (per head per day)	0.88	0.91	0.80	0.93	0.82	0.92	0.78	0.88
Egg weight (g/egg)	62.3	62.6	63.3	61.5	62.7	61.8	62.7	61.1
FCR (kg feed/kg eggs)	2.20	1.99	2.49	2.07	2.46	2.18	2.69	2.26
Feed intake (kg/head/day)	0.109	0.114	0.126	0.119	0.127	0.124	0.132	0.090
o/w compound feed incl. concentrates	96%	100%	100%	70%	100%	76%	100%	82.9%
o/w wheat own farm	4%	0%	0%	30%	0%	24%	0%	9.2%
o/w roughages	0%	0%	0%	0%	0%	0%	0%	7.9%
Start weight (kg/pullet)	1.27	1.25	1.45	1.25	1.45	1.25	1.45	1.25
End weight (kg/spent hen)	1.7	1.6	1.7	1.6	1.7	1.6	1.7	1.6
Flock mortality	5.9%	2.9%	7.6%	5.9%	11.6%	12.6%	15.9%	5.9%
Production cycle (days)	392	457	364	437	336	404	336	410
Electricity (kWh/kg egg)	0.19	0.14	0.28	0.18	0.29	0.19	0.34	0.22
Oil for heating (m3/kg egg)	-	-	-	-	-	-	-	-
Bedding material (kg/kg egg)	0	0.002	0.017	0.008	0.018	0.009	0.020	0.009
		Unspecified (assumed straw and wood shavings)	Straw and wood shaving	Straw and wood shaving	Straw and wood shaving	Straw and wood shaving	Straw and wood shaving	Straw and wood shaving
Outdoor area (m2/bird)	0	0	0	0	4	4	6	4

5.4.2 Total calculated nitrogen and methane emissions layer housing system

Nitrogen emissions layer housing system

- Input data for calculations (nitrogen-intake) was based on the nitrogen composition of the feed and the total feed intake.
- Primary data for nitrogen excretion and nitrogen stored in manure were provided by Danish Egg Association and were used for calculating nitrogen emissions.
- Calculated nitrogen emissions include direct and indirect N2O emissions, NH3 emissions, NO emissions, and N2 emissions. The share of N2O, NH3, NO and N2 emissions from the total nitrogen emitted were based on IPCC guidelines (Dong, Mangino & Jerry, 2019).

Methane emissions layer housing system for poultry manure management were based on LEAP guidelines (LEAP, 2015).

6. Results

6.1 Global warming impact

This chapter describes the results for the impact on global warming (also known as the carbon footprint) of eggs. First, the carbon footprint of layer feed is discussed, this being the main contributor in the carbon footprint of eggs. Next, the carbon footprint of the various housing systems is discussed.

6.1.1 Layer feeds

The production of compound feed for layers has a significant impact on the carbon footprint of eggs. Below shows the results for the production of compound feed for conventional and organic systems in 2000 and 2020, and roughage used in organic layer systems. Results show the contribution of the most important feed ingredients to the total impact of the feed. Each feed ingredient includes transport from country of cultivation to Denmark. The total transport of these feed ingredients adds between 0.03-0.06 kg CO2eq/kg to the carbon footprint of compound feed. The feed composition and the origin of these ingredients can have a big impact on the total carbon footprint of the feed. Soybean meal in conventional diets is cultivated in Argentina and is related to deforestation causing high land use change emissions (see chapter 3.3), whereas soybean meal in organic diets is cultivated in China for which zero land use change emissions are calculated (Blonk Consultants, 2018). This explains the main difference between the conventional and organic diets.

The conventional diet reduced with 26% from 2000 to 2020, mainly due to lower land use change emissions. The 2020 diet contains less soybean meal and oil, and the land use change impact per kilogram soybean has reduced in 2020. Furthermore, the 2020 diet contains less palm oil and maize, and more oats and wheat grain (see appendix I for the complete compound feed compositions). 'Other ingredients' contains amino acids, vitamins, minerals and other additives, as well as other feed ingredients with a contribution of less than 2% (e.g. barley, rapeseed meal). The organic diet increased with 14% from 2000 to 2020, mainly due to maize added to the diet in 2020.

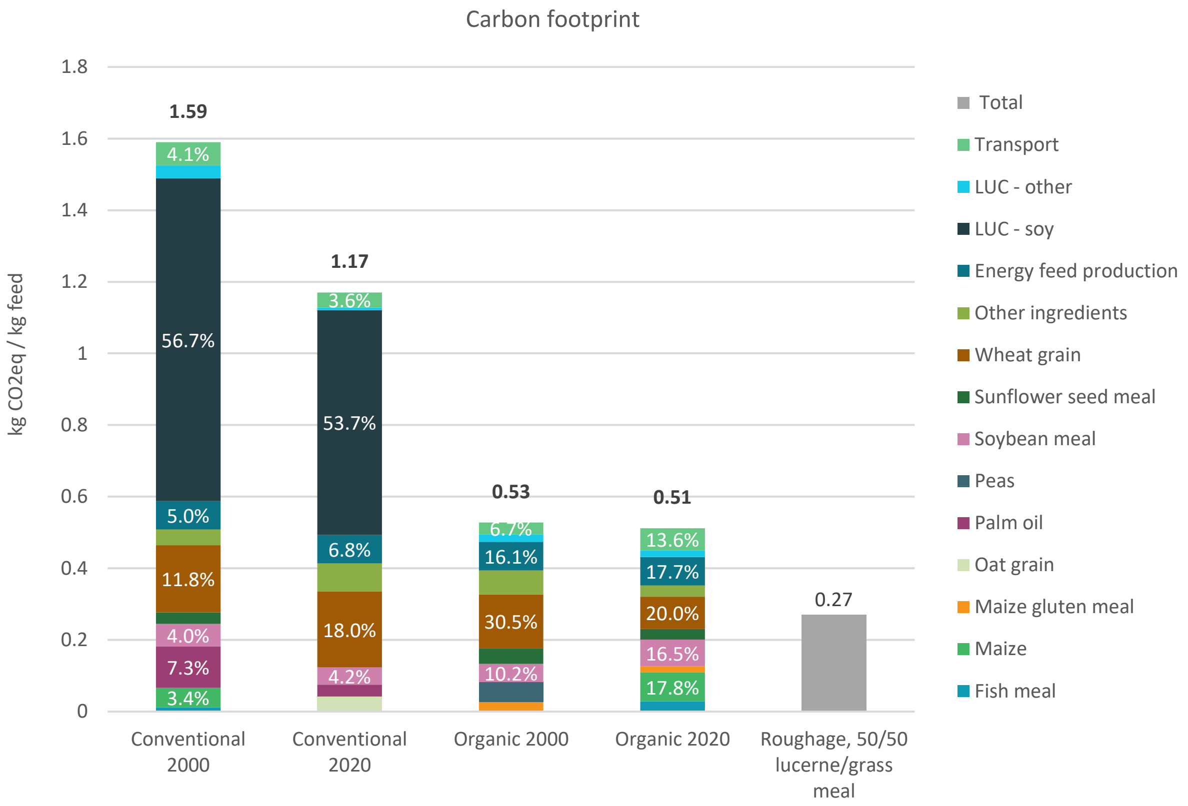

Figure 6 Carbon footprint results of layer compound feeds. Expressed in CO2 equivalents per kg feed. (LUC = land use change)

6.1.2 Egg production

Egg production in Denmark had a global warming impact of between approximately 2.3 to 4.8 kg CO2eq/kg egg in the year 2000. In 2020, the impact is significantly lower, ranging between 1.7 to 2.7 kg CO2eq/kg egg. Figure 7 shows the results per housing system and per production year. A description of each contribution group is given in Table 10.

Cage system

Cage housing systems have reduced its carbon footprint with 30% in 20 years, starting from 3.91 kg CO2eq/kg egg to 2.72 kg CO2eq/kg egg. Part of this reduction is due to the lower footprint of compound feed in 2020, as shown in Figure 6. In addition, the FCR improved from 2.20 to 1.99 kg feed/kg eggs (see Table 8). The contribution of the layer farm has decreased, because electricity consumption decreased.

Barn system

Barn housing systems have reduced its carbon footprint with 49% in 20 years, starting from 4.78 kg CO2eq/kg egg to 2.45 kg CO2eq/kg egg. Part of this reduction is due to the lower footprint of compound feed in 2020, as shown in Figure 6. In addition, the FCR improved from 2.49 to 2.09 kg feed/kg eggs (see Table 8). Besides compound feed, layers in 2020 were also fed wheat grain produced on own farmland. This contributed 10% to the total footprint.

Free-range system

Free-range housing systems have reduced its carbon footprint with 44% in 20 years, starting from 4.75 kg CO2eq/kg egg to 2.66 kg CO2eq/kg egg. Part of this reduction is due to the lower footprint of compound feed in 2020, as shown in Figure 6. In addition, the FCR improved from 2.46 to 2.18 kg feed/kg eggs (see Table 8). Besides compound feed, layers in 2020 were also fed wheat grain produced on own farmland. This contributed 8% to the total footprint.

Organic system

Organic housing systems have reduced its carbon footprint with 26% in 20 years, starting from 2.27 kg CO2eq/kg egg to 1.67 kg CO2eq/kg egg. As discussed in chapter 6.1.1, organic compound feed has a lower footprint than conventional compound feed mainly due to the absence of land use change emissions. The results for organic eggs are therefore lower than conventional egg production systems, even in the year 2000 when feed conversion was more efficient in conventional systems. The reduced impact of organic eggs from 2000 to 2020 can be explained by a decrease in FCR from 2.69 to 2.26 kg feed/kg eggs (see Table 8).

Table 9 Carbon footprint results of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in kg CO_2eq per kg egg.

	Cage 2000	Cage 2020	Barn (floor system) 2000	Barn (aviary system) 2020	Free-range (floor system) 2000	Free-range (avairy system) 2020	Organic (floor system) 2000	Organic (aviary system) 2020
Compound feed	1.36	1.06	1.61	0.76	1.59	0.88	1.39	0.95
Wheat grain (own production)	0.04	0.00	0.00	0.24	0.00	0.20	0.00	0.07
Roughages	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Layer farm	0.16	0.12	0.23	0.15	0.23	0.16	0.28	0.20
Pullets	0.21	0.16	0.30	0.19	0.33	0.22	0.37	0.27
N2O emission on-farm	0.04	0.04	0.11	0.05	0.10	0.05	0.09	0.06
CH4 emission on-farm	0.05	0.05	0.06	0.05	0.06	0.05	0.06	0.06
LUC - soybeans	1.97	1.28	2.36	0.89	2.34	1.08	0.00	0.00
LUC - other	0.08	0.02	0.10	0.12	0.10	0.02	0.08	0.04
Total	3.91	2.72	4.78	2.45	4.75	2.66	2.27	1.67
Total excl LUC	1.86	1.42	2.32	1.44	2.31	1.56	2.19	1.63

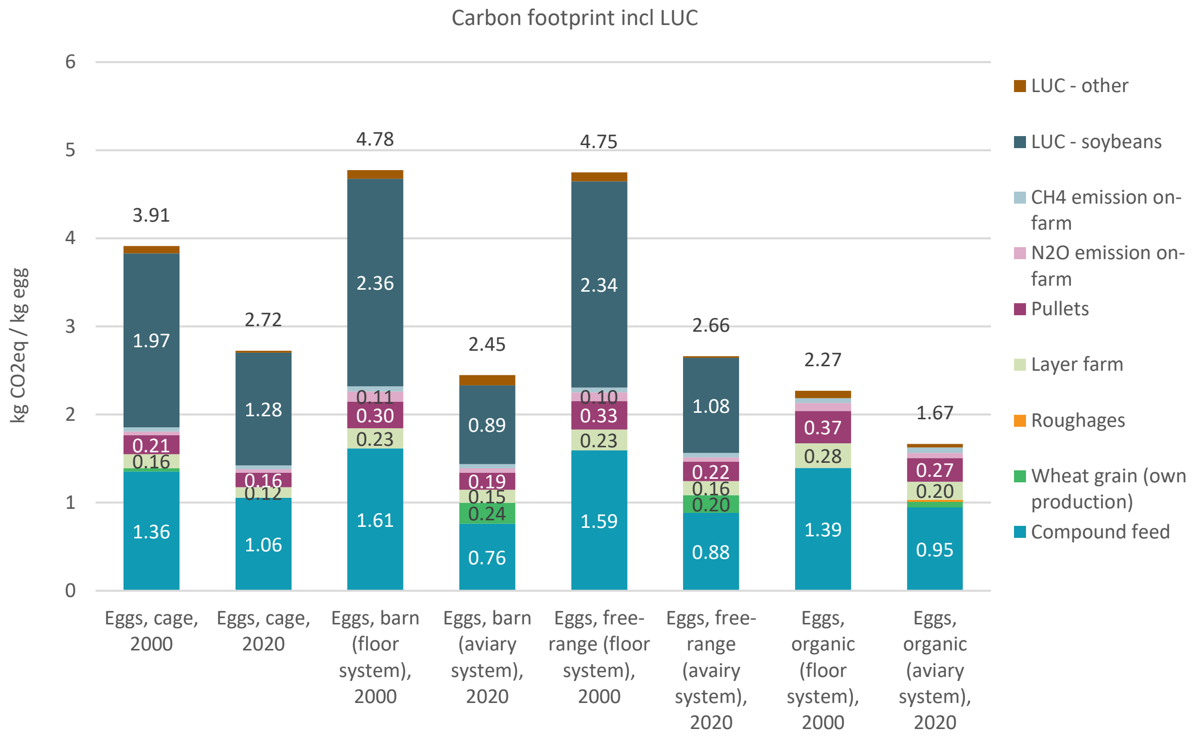

Figure 7 Carbon footprint results of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in kg CO$_2$eq per kg egg.

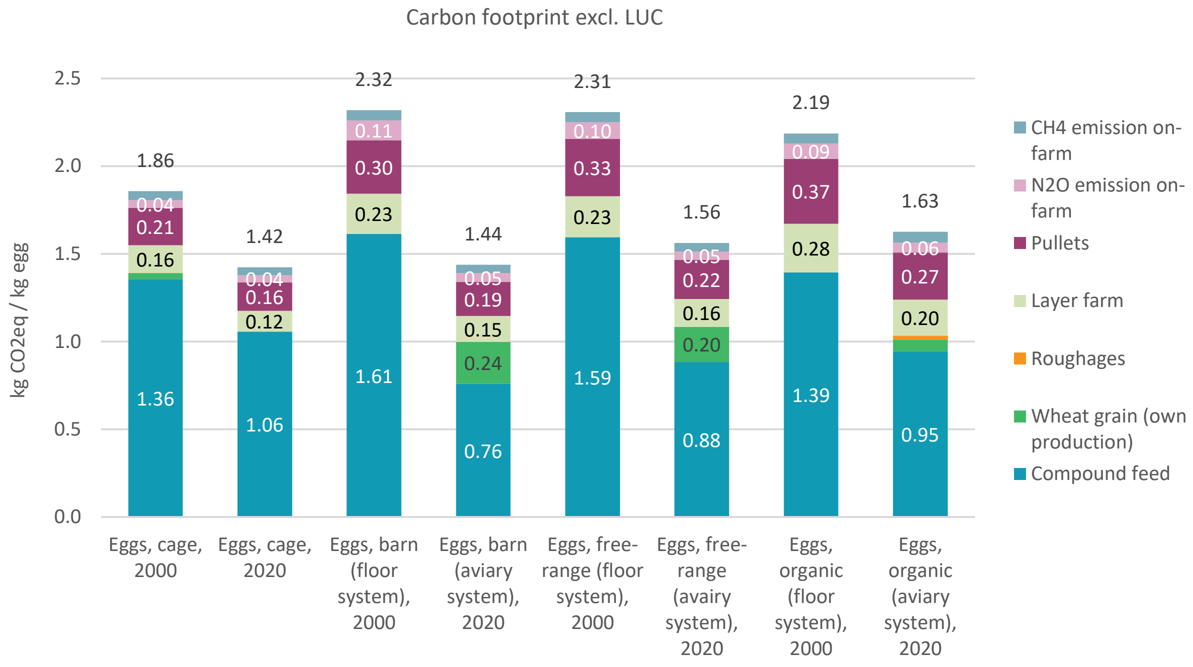

Figure 8 Carbon footprint results excluding LUC of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in kg CO$_2$eq per kg egg.

Table 10 Description of contribution groups as presented in Figure 7.

Contribution group	Description
Compound feed	*Compound feed production including the cultivation of crops, crop processing and compound feed production*
Wheat grain (own production)	*On-farm wheat cultivation, does not require transport to farm*
Layer farm	*On-farm energy and raw material use like electricity, oil, bedding material, water, and transport of pullets to layer farm*
Pullets	*Pullet rearing and transport of one-day-old chicks to rearing farm. This includes upstream stages like hatcheries and parent layers.*
N2O emission on-farm	*Direct and indirect N2O emissions from manure on layer farm based on primary data on N excretion*
CH4 emission on-farm	*CH4 emissions from manure on layer farm, based on IPCC 2019*
LUC – soybeans	*Land use change impact from soybean cultivation*
LUC – other	*Land use change impact from other crop cultivation (e.g. palm, etc)*

6.2 Land use

The impact on land use ranged from 4.00 to 8.03 m^2a/kg egg in the year 2000. In 2020, this was significantly lower, ranging from 3.19 to 4.58 m^2a/kg egg. Overall, the production of compound feed contributes most with 66%-89% of the total land use, followed by pullet rearing and wheat grains produced on own farmland. Pullet rearing itself does not require much land, but the cultivation of feed crops for pullet rearing does.

Organic eggs score higher on land use compared to conventional eggs because organic crops generally achieve lower yields per hectare, as was assumed in this study (see chapter 5.2).

The reductions per housing system are mostly due to improved feed conversion ratios and a decrease in land use per kilogram feed (see appendix III).

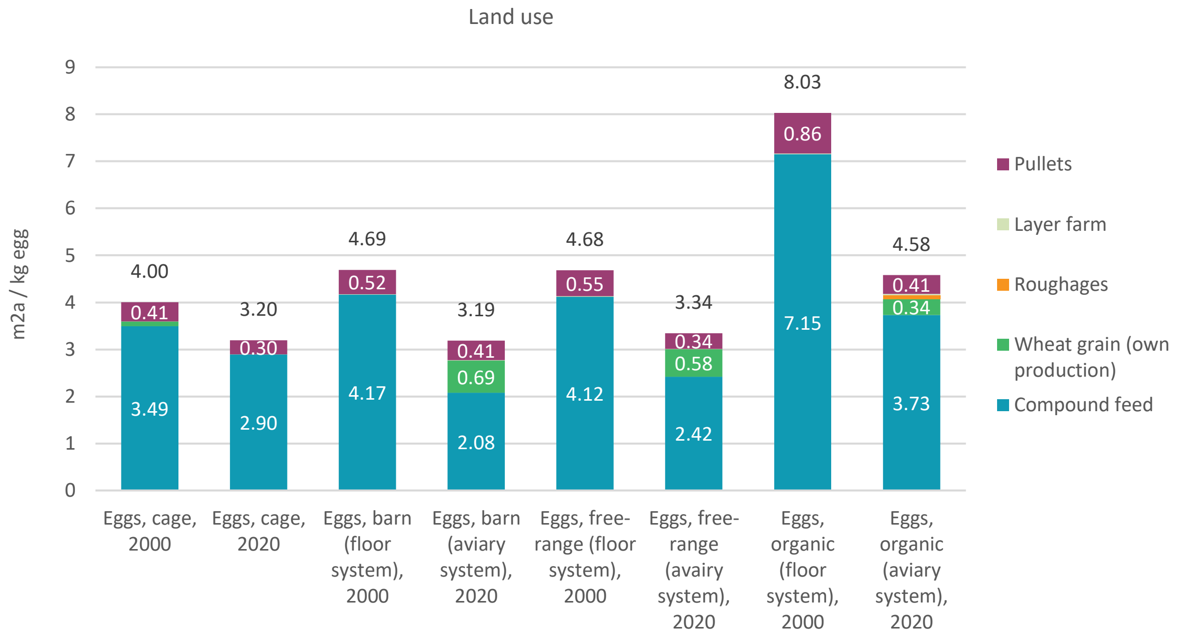

Figure 9 Land use results of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in m^2a per kg egg.

6.3 Water use and water scarcity

Water use ranged from approximately 49 to 91 litre/kg egg in the year 2000. In 2020, this was significantly lower for most egg production system, ranging from 14 to 17 litre/kg egg, except for the organic egg production system which uses 137 litre/kg egg. Although water consumption at the pullet and layer farm level has decreased between 2000 and 2020, water use is predominantly related to the production of compound feed. Organic feed has a significantly higher water use per kilogram feed compared to conventional feed (see appendix III). In 2000, high water use is mostly related to water used for the cultivation of Chinese organic soybeans. This is based on a country average of 249 m^3/ton soybeans from Mekonnen et al. (2010). In 2020, water use per kilogram organic compound feed increased from 30 to 62 liter and is caused by the cultivation of Chinese soybeans (47%) and the cultivation of maize from Ukraine (41%). Conventional compound feed on the other hand decreased its water use from 19 liter to 4 liter/kg feed. This is reflected in the results shown in Figure 10.

As mentioned in Table 1, water scarcity is expressed as the relative Available WAter REmaining (AWARE) per area in a watershed, after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived. Regions of low water availability are assigned a higher scarcity factor.

Results in Figure 11 show that especially organic eggs have a high impact on water scarcity. In 2000, 87% of the 2.48 m^3 world eq. from compound feed is caused by Chinese soybean cultivation. In 2020, 59% of the 4.29 m^3 world eq. from compound feed is caused by Chinese soybean cultivation and another 39% by maize from Ukraine. Conventional egg production has a much lower water scarcity impact due to the low scarcity factor per kilogram feed (see appendix III).

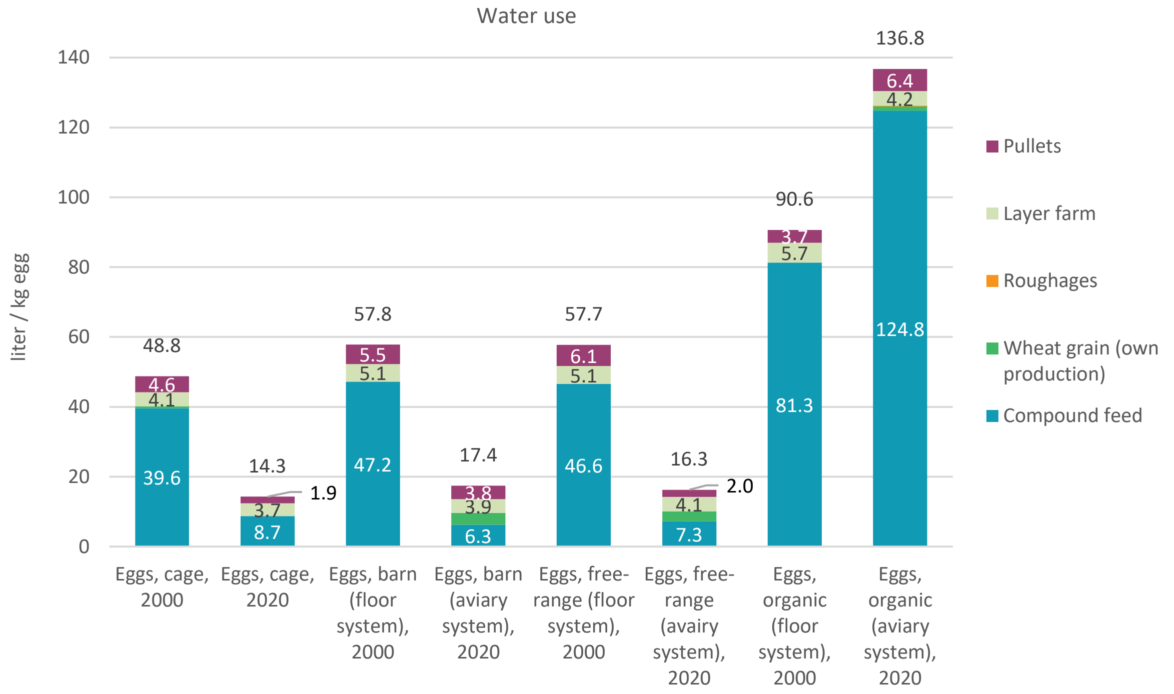

Figure 10 Water use results of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in liter per kg egg.

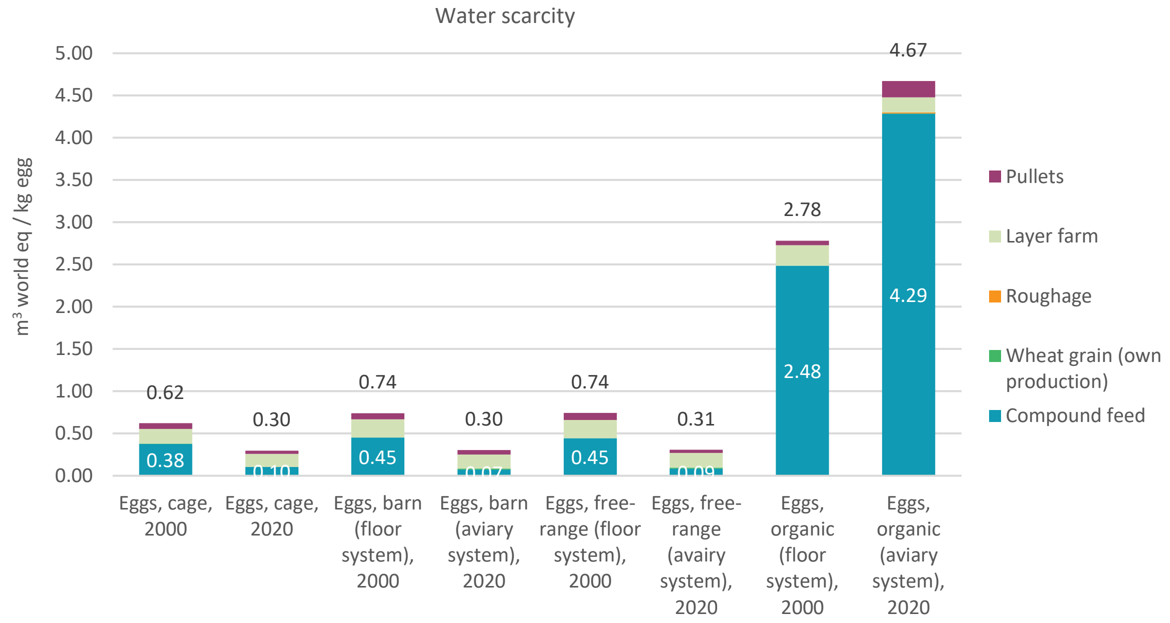

Figure 11 Water scarcity results of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in m^3 world equivalent per kg egg.

6.4 Eutrophication

The overall impact on freshwater eutrophication for cage, barn and free-range eggs has decreased from ranging between 0.29-0.34 g P-equivalents per kg eggs 2000 to 0.29-0.31 g P-equivalents in 2020 (see Figure 12). For cage eggs the difference is minimal with just 2%. Barn and free-range eggs show a more significant reduction of 7%-13%. The freshwater eutrophication impact per kg compound feed slightly increased from 2000 to 2020 (0.12 to 0.13 g P/kg feed), but due to improved FCR of cage, barn and free-range laying hens the impact per kg egg reduced from 2000 to 2020. For organic eggs, freshwater eutrophication impact decreased from 0.66 g P eq. to 0.42 P eq thanks to a reduction per kilogram feed (0.21 to 0.16 gram P eq.) and an improved FCR (see Table 8).

The main drivers for freshwater eutrophication are phosphorus emissions from fertilizer use at cultivation of feed crops. Regarding all egg production systems, the biggest contribution to freshwater eutrophication can be traced back to phosphorus emissions from wheat and maize cultivation.

Manure application for growing organic feed crops is guided by the NFRV percentage, which is the percentage of nitrogen in animal manure that is available for the crop (see chapter 5.2). This means that phosphor application follows from the amount of manure that is applied to comply with the required nitrogen content. By fulfilling the nitrogen requirements, surpluses of phosphorus and or potassium can occur. This is a consequence of the assumptions made for modelling of organic feed crops, as described in section 5.2.

The impact from pullet rearing can also be traced back to phosphorus emissions from fertilizer use for the cultivation of feed crops.

The overall impact on marine eutrophication has decreased ranging between 4.97-6.18 g N eq. in 2000 to 4.29-5.37 in 2020 (see Figure 13). The biggest decrease is found for organic eggs, which provides the highest value in 2000 and the lowest value in 2020. To illustrate this, organic eggs produced in 2020 caused 31% less impact than in 2000, compared to a 6% impact decrease for free-range eggs.

The main drivers for marine eutrophication are nitrogen emissions from fertilizer use at cultivation of feed crops. Regarding all egg production systems, the biggest contribution to marine eutrophication can be traced back to nitrogen emissions from wheat and maize cultivation.

Organic eggs show the largest reduction due to a decrease in marine eutrophication potential per kilogram compound feed. Both the layer and pullet compound feed have a lower impact in 2020 (1.58 and 1.53 gram N-eq/kg feed, respectively), compared to 2000 (1.94 and 2.01 gram N-eq/kg feed, respectively). This is explained by a change in feed composition (less wheat).

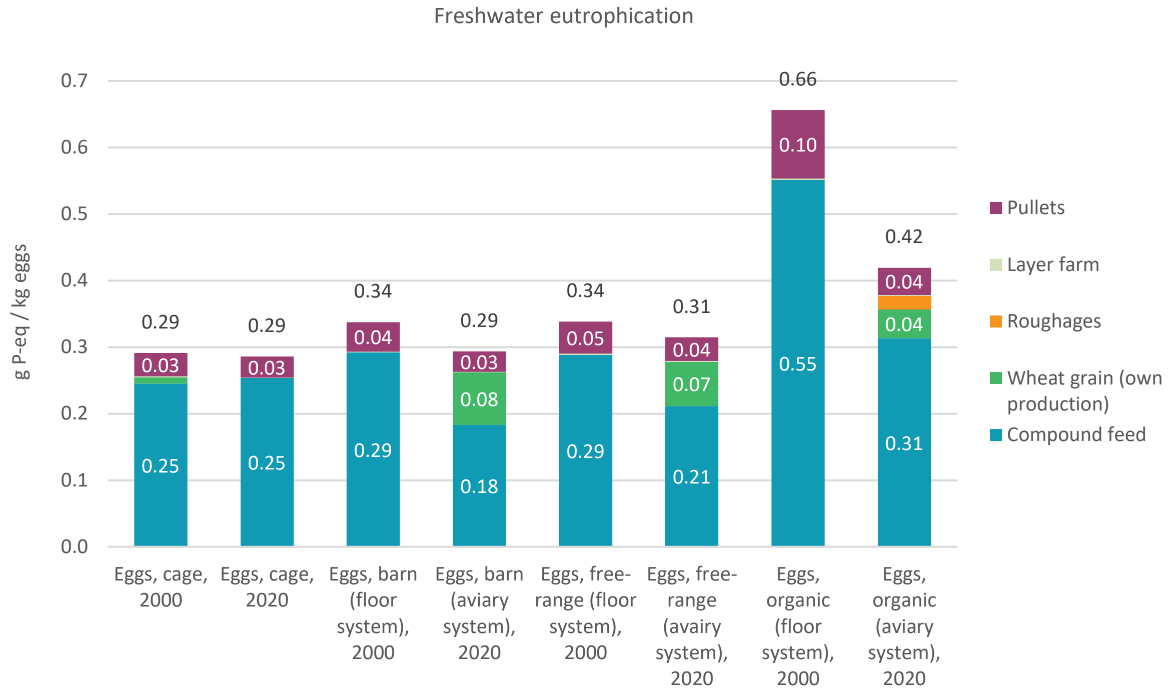

Figure 12 Freshwater eutrophication results of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in kg P equivalent per kg egg.

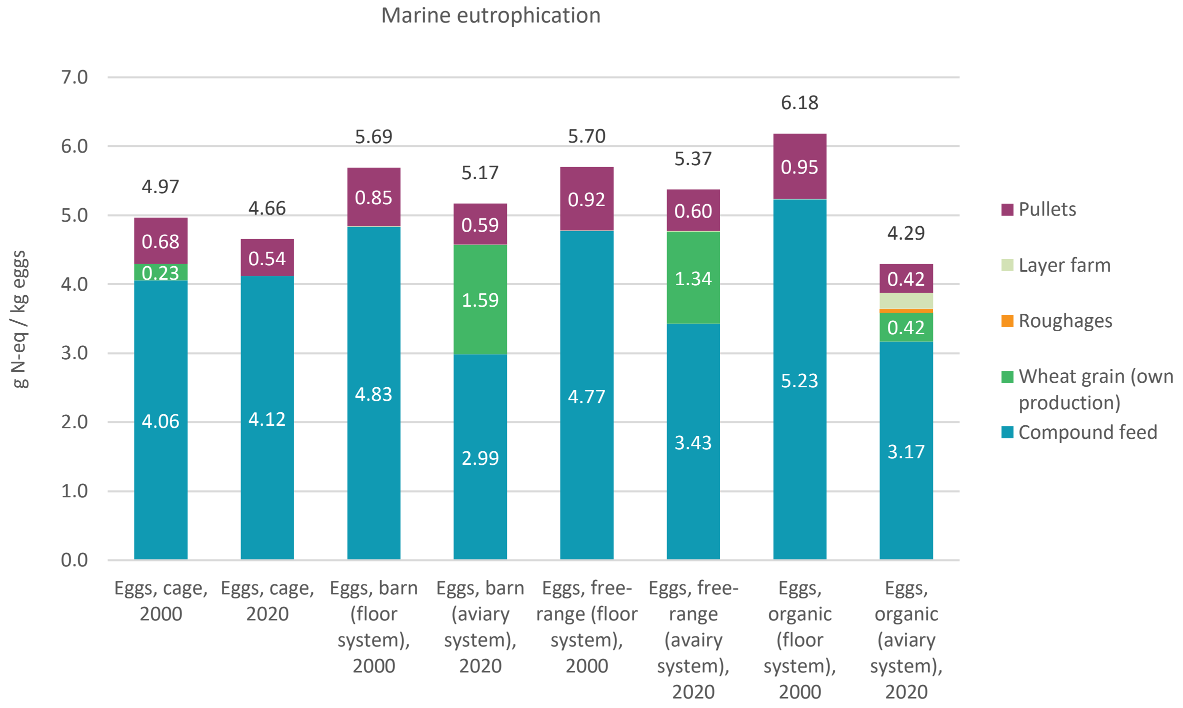

Figure 13 Marine eutrophication results of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in kg N equivalent per kg egg.

6.5 Respiratory inorganics / particulate matter

The impact on fine particulate matter (PM) formation has decreased for all eggs from 2000 to 2020.

For the year 2000, fine particulate matter impact ranged from 4.25-8.20 g PM2.5 eq., whereas for the year 2020 this impact ranges from 3.80-5.71 g PM2.5 eq./kg eggs (see Figure 14). Particulate matter formation in pullet rearing and at layer farm is mostly caused by ammonia volatilization of manure into the air.[1] Quantities of ammonia volatized are calculated based on the provided information on nitrogen excretion (see appendix II). The fact that manure is dried more frequently in 2020 housing systems reduces the ammonia emissions and therefore results in lower PM formation compared to 2000.

Particulate matter formation also occurs during crop cultivation due to fertilizer application and related ammonia and nitrous oxide emissions. This explains the contribution from compound feed and own-grown wheat indicated in Figure 14.

As particulate matter formation at farm has to be distributed over eggs produced, a lower egg yield results in a higher impact per kilogram eggs. The organic egg yield is lower than free-range, barn and cage egg yields. Therefore, particulate matter formation is higher for organic eggs systems. Additionally, there is a difference in PM formation from conventional and organic compound feeds where organic feeds have a higher impact on PM formation (see appendix III).

Please note that PM10 particles (slightly bigger than PM2.5 particles) also affect air quality and are mainly emitted from bedding material, feed and feathers at the laying farm. However, PM10 particles are not included in the ReCiPe impact assessment method applied in this study (Huijbregts et al., 2016). This because PM10 particles are considered to have a less severe impact on human health (Dekker et al., 2020).

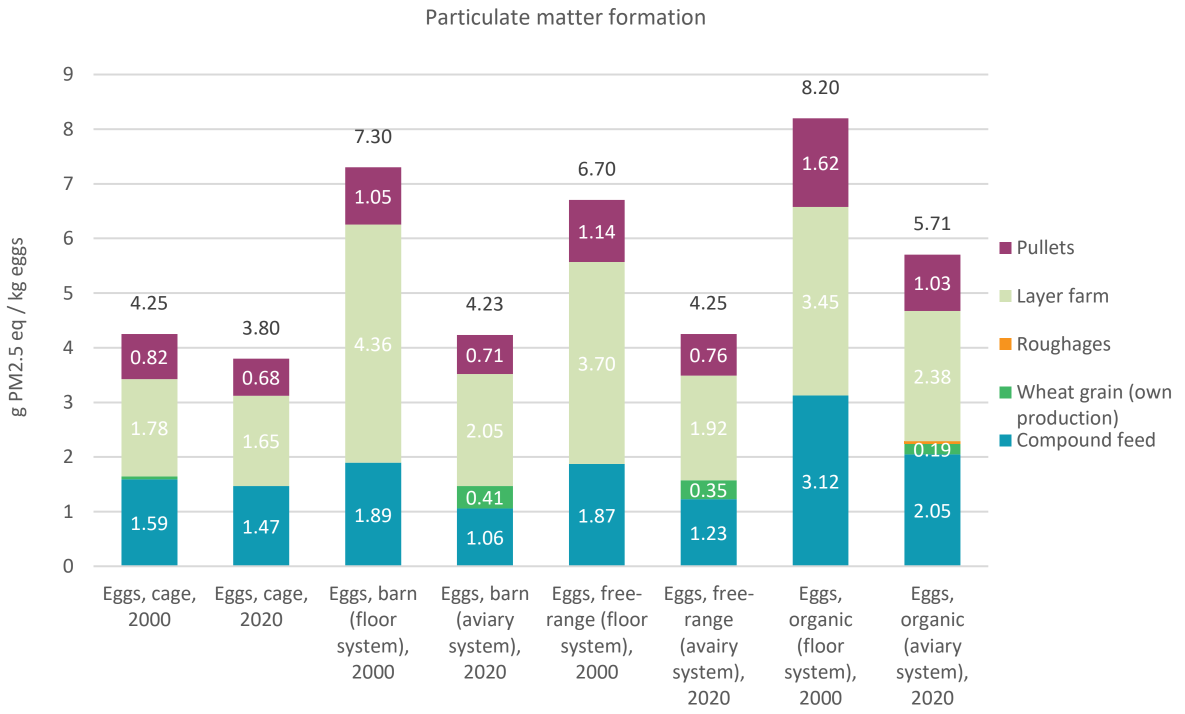

Figure 14 Particulate matter formation results of egg production in cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in grams PM2.5 equivalent per kg egg.

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[1] Atmospheric ammonia can act to neutralize the acidity of atmospheric acids, leading to the formation of inorganic aerosol (e.g., ammonium sulfate or ammonium nitrate).

7. Sensitivity analyses

7.1 Compound feed

A sensitivity analysis was performed to compare the carbon footprint impact of compound feed that includes the original formulation, to compound feed that includes ingredients of only European origin. This analysis was done for both conventional and organic feed formulations with 2020 as a reference year.

For the sensitivity analysis of conventional feed, Argentinian soybeans were replaced with the same number of Ukrainian soybeans in the feed formulation. The result is that the carbon footprint of the original conventional compound feed composition is higher than the conventional feed formulation that includes Ukrainian soy. The main contributor is land use change (LUC) which is associated to soybeans from Argentina. The exchange of Argentinian soybeans for Ukrainian soybeans shows a significant impact difference. Incorporation of Ukrainian soybeans in the feed formulation results in a 47% lower carbon footprint (see Figure 15). However, replacement with Ukrainian soy causes a 15% higher land use compared to Argentinian soy (see Figure 16).

The sensitivity analysis for organic feed crops involved the replacement of Argentinian sunflower seed meal with Ukrainian sunflower seed meal. In addition, the sensitivity to transport was checked for the Chinese soybean ingredient, by excluding transport from China to Denmark from the analysis (this because no organic soybean cultivation in Europe was available in the databases). Replacement of Argentinian sunflower seed meal with Ukrainian sunflower seed meal results in 2% higher impact on carbon footprint (from 0.02 to 0.03 kg CO2eq/kg feed, see Figure 15). The exclusion of transport from China to Denmark results in a 2% lower impact on carbon footprint (from 0.06 to 0.05 kg CO2eq/kg feed, see Figure 15). Results for land use shown in Figure 16 also show a minimal difference when replacing organic sunflower seed meal from Argentina (17% contribution) with organic sunflower seed meal from Ukraine (16% contribution).

Overall we can conclude effects are visible for conventional compound feed, but not for organic compound feed where LUC emissions are already low.

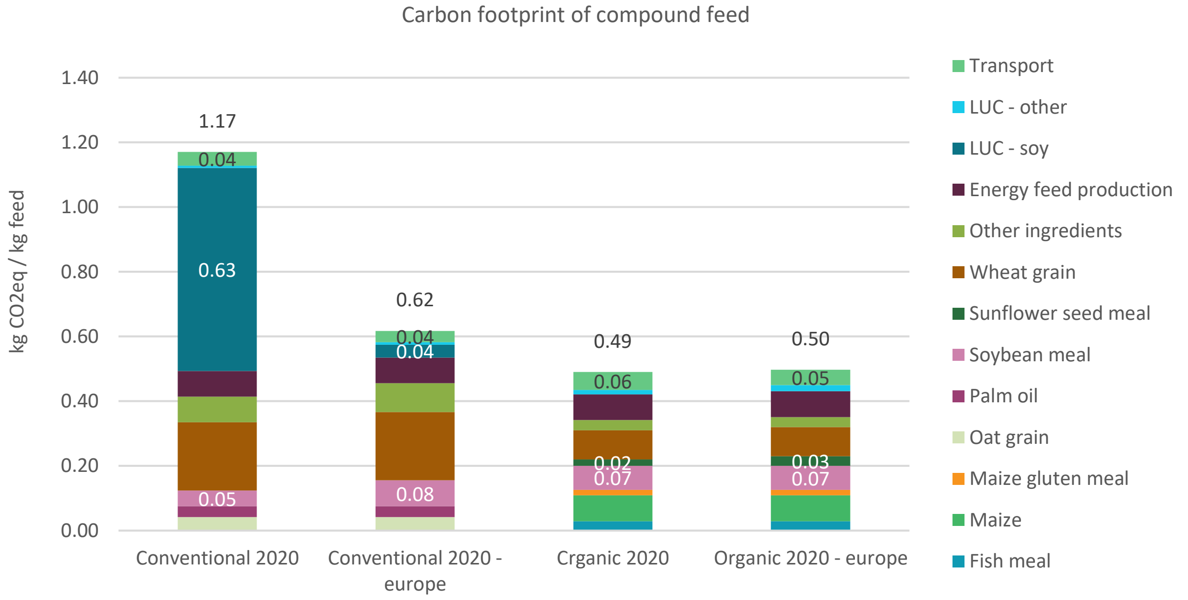

Figure 15 Carbon footprint sensitivity analysis results of compound feed for cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in kg CO2 equivalent per kg feed.

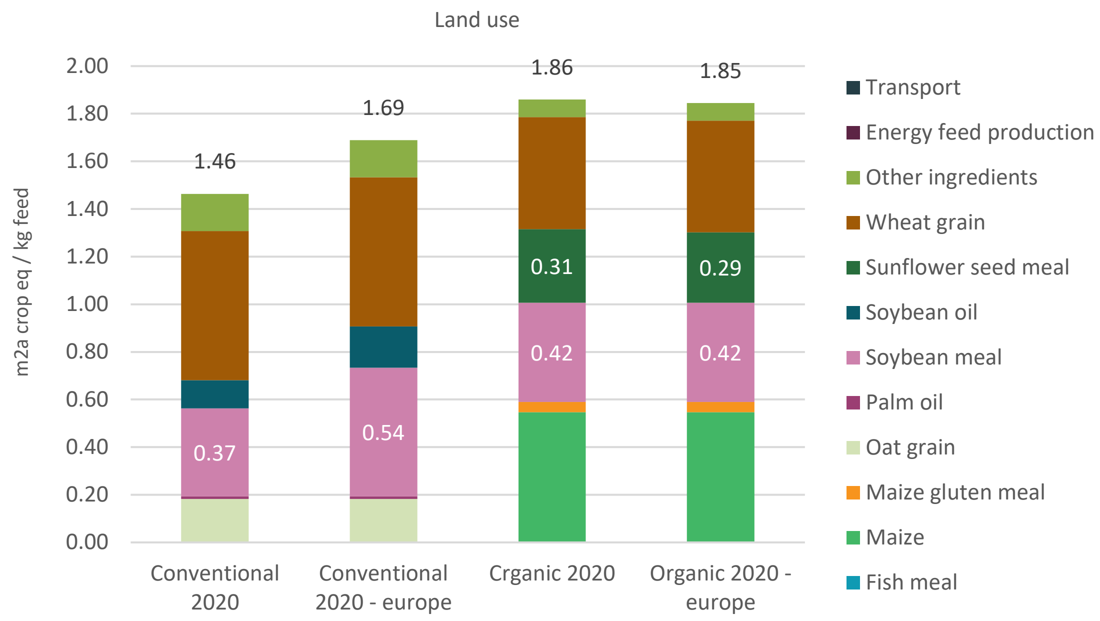

Figure 16 Land use sensitivity analysis results of compound feed for cage, barn, free-range and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in m^{2}a per kg feed

7.2 Eggs

A sensitivity analysis was performed to track the effect of replacing original feed ingredients with European feed ingredients, as presented in section 7.1. The analysis was carried out for barn (Ukrainian soy instead of Argentinian soy) and organic (Ukrainian sunflower seed meal instead of Argentinian sunflower seed meal) egg systems.

The carbon footprint of the barn eggs reflects the difference in compound feed formulation. The absence of land use change for Ukrainian soy brings about a 32% lower impact for barn eggs (see Figure 17). Nevertheless, the impact on land use is 10% higher for barn eggs that were produced using Ukrainian soy (see Figure 18).

The carbon footprint of organic eggs has not significantly changed with the absence of transport of soy from China to Denmark and the replacement of Argentinian sunflower seed meal by Ukrainian sunflower seed meal. The impact on land use has only slightly decreased (0.4%).

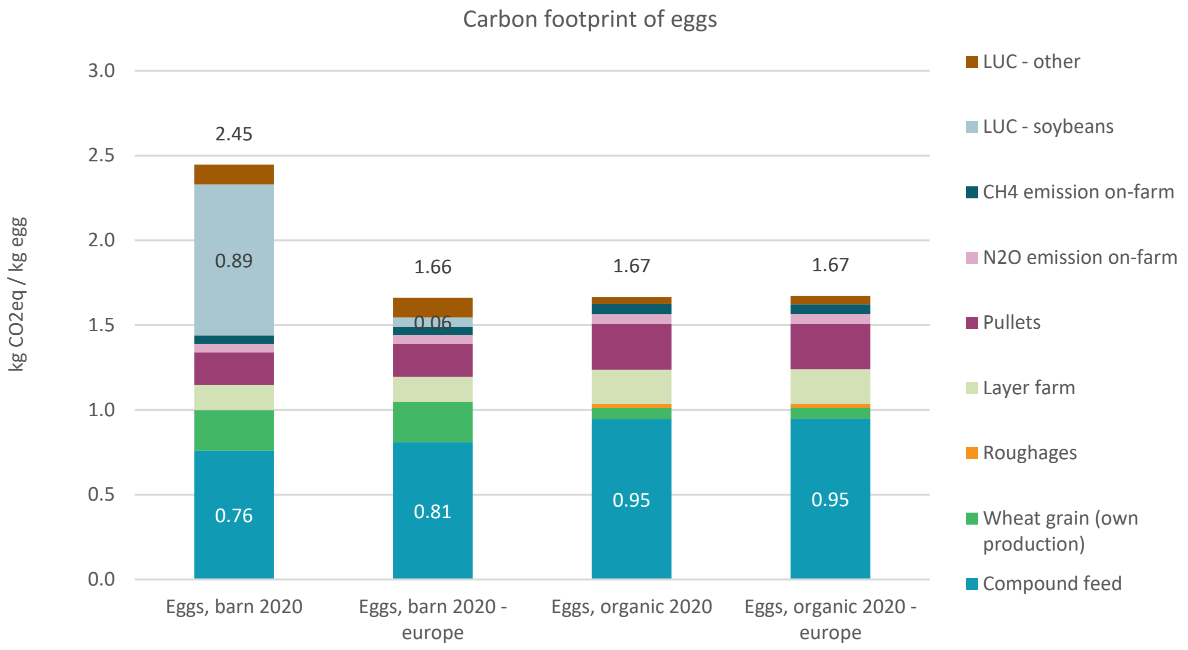

Figure 17 Carbon footprint (sensitivity to European ingredients) results of compound feed for barn and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in kg CO2 equivalent per kg eggs

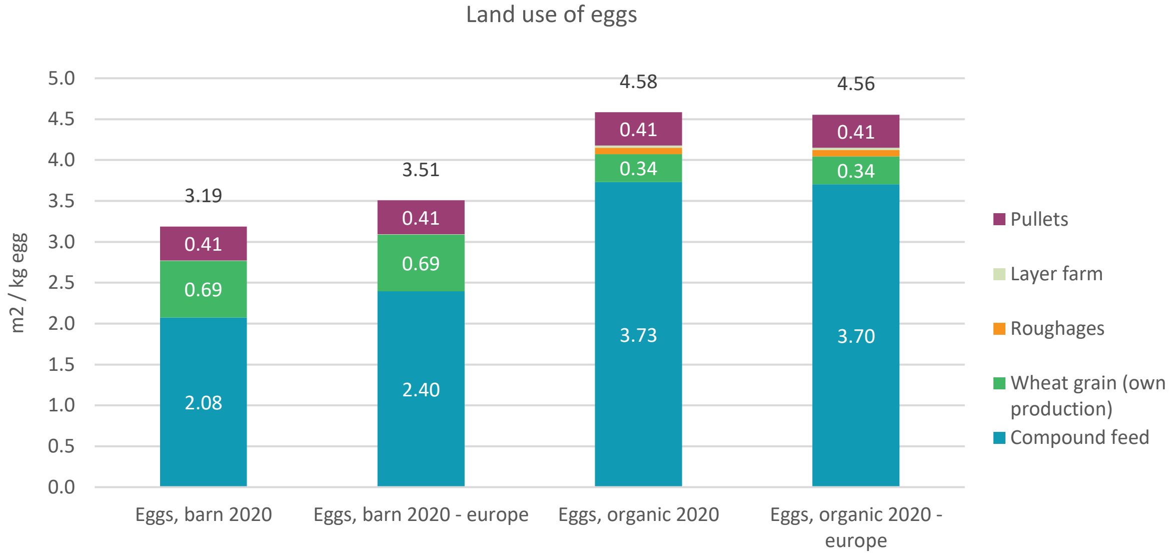

Figure 18 Land use (sensitivity to European ingredients) results of compound feed for barn and organic housing systems in Denmark in the year 2000 and 2020. Results are expressed in m2 per kg eggs

8. Conclusion

- All egg production systems increased their efficiency by lowering the feed conversion ratio. This means that less feed is required to produce a certain quantity of eggs. Since feed production is the major contributor to the climate change, eutrophication, land use, particulate matter formation and water use impact categories, improving this efficiency has led to a lower impact for all these impact categories for conventional and organic egg production systems from 2000 to 2020.

- Zooming in on the carbon footprint related to feed production for conventional egg production systems, a major reduction is related to the fact that in 2000 the production of (soybean) feed crops caused high land use change emissions. In 2020 the impact caused by land use change is significantly lower.

- The additional sensitivity analysis confirms that land use change is the most important contributing factor for the carbon footprint differences caused by (especially soybean) feed ingredients.

- The impact on land use is generally higher for organic feed crops than for conventional feed crops. This is related to the lower yields of organic crop production.

- Organic crop production is also related to a higher water consumption for irrigation and relates to a higher water stress. This is mainly related to irrigation water required for cultivation of Chinese soybeans and Ukrainian maize. Impact values for water scarcity covers the same proportions for all egg production systems, this means that water scarcity is related to water consumption and is not much affected by a difference in national water stress factors.

- Fine particulate matter formation is mainly associated with manure excretion at the pullet and layer farms. A lower impact is the result of more efficient farming systems.

- Impact on eutrophication has decreased for all egg production systems. The impact on eutrophication is mostly related to the cultivation stage of feed crops. Especially feed crops with a higher straw to grain ratio (wheat, maize) require more fertilizer to produce a similar quantity of grain compared to feed crops with a lower straw to grain ratio.

9. Recommendations

- Since the environmental impact of eggs is foremost determined by the environmental impact of feed, it is important to maintain vigilance to the data availability and quality of feed ingredients, and more specifically of feed crops. Improving data-availability and quality can be ventured by the collection of primary data from the crop cultivation stage. This is especially relevant for organic feed crops, as the selected approach may be representative, but validated information on organic feed production remains a data gap.
- For drawing firm conclusions and for communication of environmental of Danish eggs to a wider public, it is recommended to perform an external review. An external review can be performed by an external panel of experts. This panel should include, first of all, at least one LCA expert of an independent organisation. In addition, the panel should include a member whose expertise is consistent with the relevant scientific discipline(s). The external review produces a review statement and a review panel report.

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Appendix I Feed composition tables

Conventional systems

Table 11 Compound feed composition for pullets in cage, barn and free-range, 2000.

Feed ingredient	Qty	Unit
Maize, conventional 2000, FR	0.09	kg
Wheat grain, conventional 2000, DK	0.6	kg
Soybean meal (solvent), conventional 2000, AR	0.087	kg
Oat grain, conventional 2000, DK	0.1	kg
Wheat bran, from dry milling, conventional 2000, DK	0.0364	kg
Sunflower seed meal (solvent), conventional 2000, UA	0.05	kg
Soybean oil (solvent), conventional 2000, AR - DE	0.005	kg
Salt, as sodium chloride	0.002	kg
Limestone, crushed,	0.014	kg
Mono-calcium phosphate MCP	0.005	kg
DL-methionine	0.001	kg
Enzymes	0.0003	kg
L-threonine	0.0004	kg
Minerals, additives, vitamins mix	0.005	kg
Sodium bicarbonate	0.0023	kg
L-Lysine	0.0016	kg
Total	1	kg

Table 12 Compound feed composition for pullets in cage, barn and free-range, 2020.

Feed ingredient	Qty	Unit
Maize, conventional 2020, FR	0.0019	kg
Wheat grain, conventional 2020, DK	0.60	kg
Soybean meal (solvent), conventional 2020, AR	0.0323	kg
Oat grain, conventional 2020, DK	0.1646	kg
Wheat bran, from dry milling, conventional 2020, DK	0.0386	kg
Sunflower seed meal (solvent), conventional 2020, DK	0.0323	kg
Barley grain, conventional 2020, DK	0.050	kg
Palm oil, conventional 2020, MY - DE	0.005	kg
Salt, as sodium chloride	0.0015	kg
Limestone, crushed	0.0144	kg
Mono-calcium phosphate MCP	0.0058	kg
DL-methionine	0.0012	kg
Enzymes	0.0003	kg
L-threonine	0.0003	kg
Minerals, additives, vitamins mix	0.003	kg
Sodium bicarbonate	0.0032	kg
L-Lysine	0.0015	kg
Total	1	kg

Table 13 Compound feed composition for layers in cage, barn and free-range, 2000.

Feed ingredient	Qty	Unit
Maize, conventional 2000, FR	0.15	kg
Wheat grain, conventional 2000, DK	0.45	kg
Soybean meal (solvent), conventional 2000, AR	0.18	kg
Sunflower seed meal (solvent), conventional 2000, UA	0.05	kg
Soybean oil (solvent), conventional 2000, AR - DE	0.01	kg
Salt, as sodium chloride	0.00	kg
Limestone, crushed	0.06	kg
Mono-calcium phosphate MCP	0.01	kg

DL-methionine	0.0016	kg
Minerals, additives, vitamins mix	0.0055	kg
Sodium bicarbonate	0.0021	kg
Palm oil, conventional 2000, MY - DE	0.022	kg
Fish meal	0.01	kg
Grass meal, conventional 2000, DK	0.02	kg
Total	1	kg

Table 14 Compound feed composition for layers in cage, barn and free-range, 2020.

Feed ingredient	Qty	Unit
Palm oil, conventional 2020, MY - DE	0.0068	kg
Wheat grain, conventional 2020, DK	0.5500	kg
Soybean meal (solvent), conventional 2020, AR	0.1419	kg
Oat grain, conventional 2020, DK	0.1002	kg
Sunflower seed meal (solvent), conventional 2020, UA	0.0121	kg
Soybean oil (solvent), conventional 2020, AR - DE	0.0164	kg
Rapeseed meal (solvent), conventional 2020, PL	0.0359	kg
Barley grain, conventional 2020, DK	0.0431	kg
Salt, as sodium chloride	0.0019	kg
Limestone, crushed	0.046	kg
Mono-calcium phosphate MCP	0.0071	kg
DL-methionine	0.0018	kg
L-threonine	0.0001	kg
Minerals, additives, vitamins mix	0.003	kg
Sodium bicarbonate	0.002	kg
L-lysine	0.0013	kg
Total	1	kg

Organic systems

Table 15 Compound feed composition for organic pullets, 2000.

Feed ingredient	Qty	Unit
Barley grain, organic 2000, DK	0.082	kg
Oat grain, organic 2000, DK	0.12	kg
Wheat grain, organic 2000, DK	0.5	kg
Peas, dry, organic 2000, DK	0.078	kg
Rapeseed, organic 2000, DK	0.02	kg
Grass meal, organic 2000, DK	0.02	kg
Sunflower cake, organic 2000, UA	0.12	kg
Fish meal	0.03	kg
Salt, as sodium chloride	0.0024	kg
Limestone, crushed	0.013	kg
Mono-calcium phosphate MCP	0.010	kg
Sodium bicarbonate	0.0009	kg
Minerals, additives, vitamins mix	0.004	kg
Total	1	kg

Table 16 Compound feed composition for organic pullets, 2020.

Feed ingredient	Qty	Unit
Oat grain, organic 2020, DK	0.20	kg
Wheat grain, organic 2020, DK	0.30	kg
Wheat bran, from dry milling, organic 2020, DK	0.06	kg
Grass meal, organic 2020, DK	0.03	kg
Soybean expeller (pressing), organic 2020, CN	0.06	kg
Rapeseed oil, organic 2020, UA	0.03	kg
Sunflower cake, organic 2020, UA	0.01	kg
Maize, organic 2020,	0.24	kg

Maize gluten meal dried, organic 2020, at feed processing/DK Economic	0.01	kg
Fish meal, at processing/DK Economic | DEA	0.03	kg
Salt, as sodium chloride, at plant/RER Economic	0.0024	kg
Limestone, crushed, washed {RoW}| market for limestone, crushed, washed | APOS, S | DEA	0.0126	kg
Mono-calcium phosphate MCP, at plant/RER Economic | DEA	0.0101	kg
Sodium bicarbonate	0.0004	Kg
Minerals, additives, vitamins mix	0.004	Kg
Total	1	kg

Table 17 Compound feed composition for organic layers, 2000.

Feed ingredient	Qty	Unit
Barley grain, organic 2000, DK	0.05	kg
Wheat grain, organic 2000, DK	0.46	kg
Peas, dry, organic 2000, DK	0.15	kg
Grass meal, organic 2000, DK	0.02	kg
Soybean expeller (pressing), organic 2000, CN	0.10	kg
Rapeseed oil (solvent), organic 2000, DK	0.01	kg
Sunflower cake, organic 2000, UA	0.06	kg
Maize gluten meal dried, organic 2000, FR	0.05	kg
Salt, as sodium chloride	0.0024	kg
Limestone, crushed	0.085	kg
Mono-calcium phosphate MCP	0.013	kg
Enzymes	0.0007	kg
Sodium bicarbonate	0.0008	kg
Minerals, additives, vitamins mix	0.004	kg
Total	1	kg

Table 18 Compound feed composition for organic layers, 2020.

Feed ingredient	Qty	Unit
Wheat grain, organic 2020, DK	0.30	kg
Maize, organic 2020, UA	0.30	kg
Wheat bran, from dry milling, organic 2020, UA	0.00	kg
Grass meal, organic 2020, DK	0.02	kg
Soybean expeller (pressing), organic 2020, CN	0.15	kg
Rapeseed expeller (pressing), organic 2020, DK	0.01	kg
Sunflower cake, organic 2020, AR - DE	0.07	kg
Maize gluten meal dried, organic 2020, DK	0.03	kg
Fish meal	0.0246	kg
Salt, as sodium chloride	0.0014	kg
Limestone, crushed	0.0444	kg
Mono-calcium phosphate MCP	0.0105	kg
Enzymes	1.00E-04	kg
Sodium bicarbonate	0.0015	kg
Minerals, additives, vitamins mix	0.004	Kg
Total	1	kg

Appendix II Nitrogen excretion data

Table 19 Nitrogen excretion data for layers and the calculated N emissions per hen per round.

	Cage 2000	Cage 2020	Barn 2000	Barn 2020	Free-range 2000	Free-range 2020	Organic 2000	Organic 2020
kg N excretion per hen per round	0.776	0.877	0.934	0.94	0.814	0.893	0.889	1.03
kg N per hen that is stored in manure and emitted outside	0.594	0.672	0.53	0.691	0.496	0.683	0.611	0.791
Kg N emitted per hen per round	0.182	0.205	0.404	0.249	0.318	0.210	0.278	0.242

Appendix III Summarized results

Table 20 Environmental impact results for 1 kg of compound feed

		Conventional 2000	Conventional 2020	Organic 2000	Organic 2020
Carbon footprint	kg CO2eq	1.59	1.17	0.53	0.49
Carbon footprint (excl. LUC)	kg CO2eq	0.65	0.54	0.51	0.48
Land use	m2	1.66	1.46	2.51	1.86
Water consumption	liter	19.20	4.43	30.38	61.57
Water scarcity	m^3 world eq	0.18	0.05	0.93	2.12
Fine particulate matter formation	g PM2.5 eq	0.77	0.75	1.14	1.02
Freshwater eutrophication	g P eq	0.12	0.13	0.21	0.16
Marine eutrophication	g N eq	1.96	2.10	1.94	1.58

Table 21 Environmental impact results for 1 kg of eggs

		Cage, 2000	Cage, 2020	Barn (floor system), 2000	Barn (aviary system), 2020	Free-range (floor system), 2000	Free-range (aviary system), 2020	Organic (floor system), 2000	Organic (aviary system), 2020
Carbon footprint	kg CO2eq	3.91	2.72	4.78	2.45	4.75	2.66	2.28	1.66
Carbon footprint (excl LUC)	kg CO2eq	1.86	1.42	2.32	1.44	2.31	1.56	2.19	1.62
Land use	m2	4.00	3.20	4.69	3.19	4.68	3.34	8.03	4.58
Water consumption	liter	48.79	14.28	57.80	17.39	57.72	16.28	90.64	136.77
Water scarcity	m^3 world eq	0.62	0.30	0.74	0.30	0.74	0.31	2.78	4.67
Fine particulate matter formation	g PM2.5 eq	4.25	3.80	7.30	4.23	6.70	4.25	8.20	5.71
Freshwater eutrophication	g P eq	0.29	0.29	0.34	0.29	0.34	0.31	0.66	0.42
Marine eutrophication	g N eq	4.97	4.66	5.69	5.17	5.70	5.37	6.18	4.29

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Blonk Consultants
Groen van Prinsterersingel 45
2805 TD Gouda

+31 (0) 182 579970
www.blonkconsultants.nl
info@blonkconsultants.nl

blonk›consultants‹