NORSUS
Norwegian Institute for
Sustainability Research

Life Cycle Assessment of meat and egg - Nortura

AUTHOR(S)
HANNE MØLLER
STINE SAMSONSTUEN

REPORT NO.
OR 29.23

YEAR
2023

ISBN NO.	**ISSN NO.**	**REPORT TYPE**	**CONFIDENTIALITY**
978-82-7520-920-5	2703-8610	Commissioned report	open

PROJECT TITLE

LCA of meat

PROJECT NUMBER

3199

COMMISSIONED BY

Nortura SA

INTERNAL QUALITY CONTROL

Anna Woodhouse

NUMBER OF PAGES

66 pages

KEY WORDS

LCA, meat, egg, environmental impacts

PHOTO FRONTPAGE

Photos of animals and eggs by unknown authors, accessed 5 September 2023. Licensed under CC BY-SA.

Summary

Nortura has commissioned NORSUS to carry out a life cycle analysis (LCA) of Norwegian production of meat and eggs. LCA is a method for quantifying the environmental impacts of a product system.

The data is based on 2021 and calculated for 1 kg carcass from beef from dairy cattle, beef from beef cattle, mutton and lamb, pork, turkey, chicken, and 1 kg of egg. The environmental impact of meat and egg produced in Norway is based on the average production levels in Norway.

The table below shows the total environmental impacts for all animal species per kg carcass and egg.

Total environmental impacts per kg carcass and kg egg from cradle to industry gate.

Impact category and unit	Beef dairy cattle	Beef beef cattle	Mutton and lamb	Pork	Chicken	Turkey	Egg
GHG total (kg CO_2 eqv)	21.6	30.0	26.1	3.2	2.3	2.4	1.5
GHG biogenic (kg CO_2 eqv)	10.2	16.3	11.7	0.7	0.1	0.2	0.1
GHG fossil (kg CO_2 eqv)	11.0	13.6	14.3	2.5	2.1	2.1	1.4
GHG LULUC (kg CO_2 eqv)	0.5	0.1	0.1	0.04	0.04	0.07	0.05
Land occupation, excl. outfields (m^2)	27	28	28	6.5	4.4	6.4	3.6
Biodiversity (PDF)	7.0	-14	-41	4.3	2.9	4.1	2.4
Eutrophication, marine (kg N eqv)	0.05	0.04	0.06	0.01	0.01	0.01	0.01
Eutrophication, freshwater (kg P eqv)	0.014	0.011	0.011	8.6E-04	6.2E-04	5.9E-04	4.1E-04
Eutrophication, terrestrial (mol N eqv)	1.9	2.5	1.8	0.23	0.12	0.36	0.12
Particulate matter (disease inc.)	2.7E-06	3.8E-06	2.4E-06	4.3E-07	2.0E-07	6.0E-07	2.0E-07
Acidification (mol H+ eqv)	0.41	0.56	0.39	0.06	0.03	0.08	0.03
Water use (m^3 depriv.)	1.8	0.58	0.76	0.51	2.1	1.8	1.4

For the ruminant's dairy cattle, beef cattle and sheep, a large part of the greenhouse gas emissions (GHG) arises from enteric methane. A large part also comes from N_2O from housing and manure storage. For the monogastric animals' pig, chicken, turkey and laying hen, N_2O from use of fertiliser and CO_2 emissions from feed production make up the largest proportion of greenhouse gases. In addition, a varying proportion comes from methane and N_2O from housing and manure storage.

For particulate matter and acidification, the largest emissions occur in feed production and housing and manure storage and the same applies to the various eutrophication categories.

Feed production for monogastric animals takes place exclusively on arable land. For dairy cattle, the feed production is mainly linked to grassland for grass silage production and pasture but also arable land for grain production. For beef cattle and sheep, a larger part of the feed is sourced from grazing in permanent pasture and outfields. Loss of biodiversity is assessed based on plant species richness. Because beef cattle and sheep production are based on a large proportion of grazing, these productions contribute to increased biodiversity. Correspondingly, the use of areas for grass production in cereal crop rotation will result in loss of biodiversity. Because most of the feed for dairy cattle and monogastric livestock comes from such areas, the net contribution from these productions will result in a loss of biodiversity.

The differences in water use are mainly due to feed production, especially the poultry feed contains imported feed ingredients which have an impact because the characterization factors are regionalized for water in the AWARE (Available WAter Remaining) method, i.e. they take into account the availability of water in each individual country.

The results for meat in this study are calculated for kg carcass. It is also relevant to calculate environmental impacts for boneless meat and work is underway to provide good and reliable conversion factors for each animal species. In addition, allocation factors must also be calculated for by-products from the slaughtering process, so that the total environmental burden can be distributed to all the outputs from the slaughterhouse based on their economic value.

The results are a documentation of the environmental impact from current livestock production and includes several impact categories such as climate change, land occupation, biodiversity, eutrophication, particulate matter, and gives a starting point for discussing and evaluating future measures for improving the sustainability of the value chain.

Contents

1 Introduction

Nortura has commissioned NORSUS to carry out a life cycle analysis (LCA) of Norwegian production of meat and eggs. The data is based on 2021 and calculated for 1 kg carcass from beef from dairy cattle, beef from beef cattle, mutton and lamb, pork, turkey, chicken, and 1 kg of egg. The results are a documentation of the current production and gives a starting point for future measures for improving the sustainability of livestock production.

LCA is a method for quantifying the environmental impacts of a product system or a service for the value chain (life cycle). In an LCA the entire life cycle can be included in a so called “cradle to grave analysis” or part of the life cycle can be assessed, such as “cradle to industry gate of Nortura”, as in this study. The method makes it possible to assess several environmental impacts for a given system. There are several international standards guidelines that provide overall principles and calculation rules for carrying out LCA analyses.

2 Method

Life cycle assessment (LCA) is a method that models parts of or the entire value chain (life cycle) for a product or a system that is function-oriented and is used to quantify several environmental impacts. The LCA models used in this report was developed as a part of the project LIVESTOCK. Detailed information about the models can be found in the relevant publications (Møller et al., 2022; Samsonstuen et al., 2023). The farm models of meat and egg production included processes from cradle to farm gate production, and off-farm production of e.g., imported feed, fertilizer, transport, energy, and inputs used on the farm. In this assignment the slaughterhouse process was added and thus extended to a cradle to industry gate analysis.

2.1 Goal and scope

The purpose of the study was to calculate the environmental impacts for production of meat and egg. The system boundaries were cradle to gate of Nortura, see Figure 1. Each livestock system includes rearing of the parent generation and young animals until slaughter.

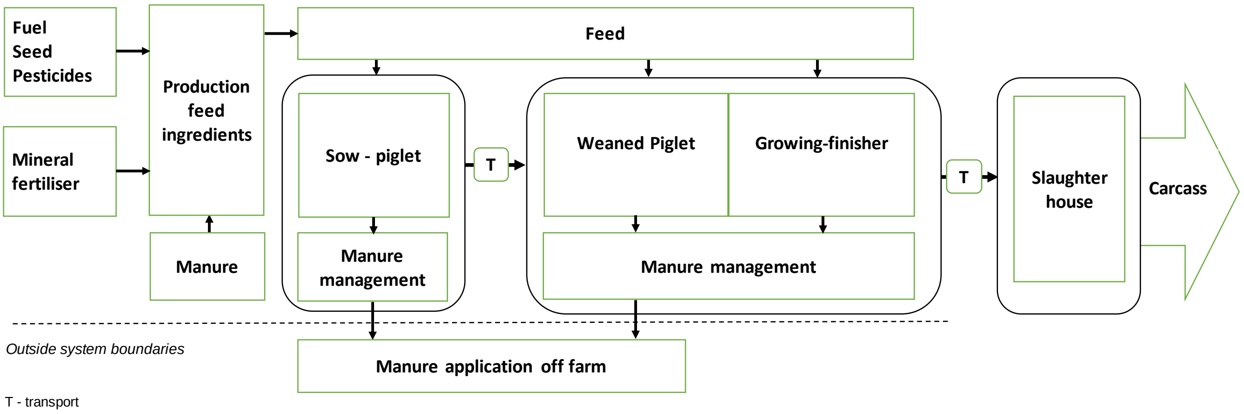

Figure 1 General system description for the pig production system. Similar system boundaries are used for beef from dairy cattle, beef from beef cattle, mutton and lamb, pork, turkey, chicken, and egg.

2.2 Functional unit

The functional unit was defined as 1 kg carcass from beef from dairy cattle, beef from beef cattle, mutton and lamb, pork, turkey, chicken, or 1 kg of egg and includes cradle to industry gate of Nortura.

2.3 Allocation

Allocation means distributing the emissions and environmental impacts from a process between several outputs. If it is not possible to avoid allocation, inflows and outflows must be allocated in a way that reflects the underlying physical conditions between them. The choice of allocation method is based on recommendations in the PEFCR:

For feed and plant production, economic allocation has been used for co-products on the farm (e.g., rapeseed oil and rapeseed meal) and follows the PEFCR for feed (FEFAC, 2018). Economic allocation has also been used for distribution of impact between sheep meat and wool.

Allocation between milk and meat on the farm is based on biophysical principles according to PEFCR Dairy products (European Dairy Association, 2018) and which has also previously been recommended by the IDF.

Allocation factor milk = $1 - 6.04\ x\ \frac{Mmeat}{M\ milk}$

where Mmeat is the mass of live weight of all animals sold including bull calves and culled mature animals per year, and Mmilk is the mass of fat and protein corrected milk (FPCM) sold per year (corrected to 4% fat and 3.3% protein).

2.4 Emissions factors

Characterisation method (EF 3.1, IPCC 2013 and 2021) and the stepwise approach by Carbon Limits for calculation of methane and atmospheric nitrogen emissions from manure have been used. Available nitrogen and volatile solids in the manure was estimated according to Karlengen et al. (2012) and was the basis for calculation of methane (CH_4) and atmospheric nitrogen emissions from manure, which follow the step-wise approach described in detail by Carbon Limits (2020a, 2020b), see Figure 2. Direct nitrous oxide N_2O emissions from manure storage are calculated by multiplying the N content in manure by an emission factor for the manure handling system. Indirect N_2O emissions from evaporation of NH_3 and NOx are calculated as a proportion of NH_3 and NOx losses from barns and manure storage. For cattle and sheep, enteric CH_4 emissions are calculated using an IPCC (2006) Tier 2 approach as described in detail by (Samsonstuen et al., 2023). For monogastrics, a IPCC (2006) Tier 1 methodology is used for enteric CH_4.

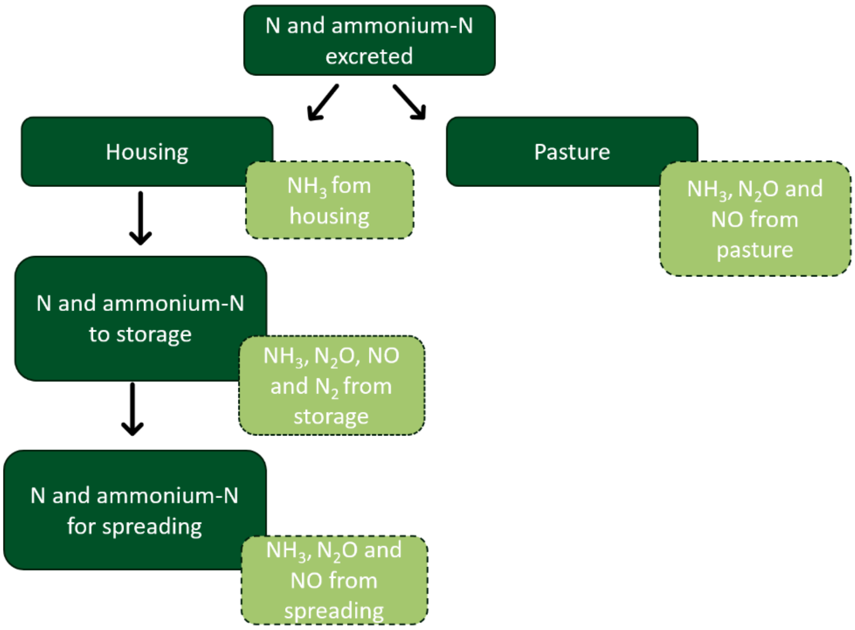

Figure 2 Simplified overview over the step-wise calculation of atmospheric nitrogen emission from housing and manure storage based on Carbon Limits (2020a).

2.5 Impact categories

2.5.1 Climate change

The climate change potential is reported as an aggregated value and separately for the sub-indicators Climate change fossil, Climate change biogenic and Climate change land use and land use change (LULUC).

The emission of greenhouse gases measured in CO_2 equivalents, also called global warming potential (GWP). A 100-year time horizon has been used, as it is the conventional cut-off time in LCA climate change modelling. The results in this report are shown for characterization factors based on IPCC 2021 but because the choice of these may have significance on the results, results are also shown in the Appendix based on IPCC 2013.

The on-farm GHG emissions included direct emissions of methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) from livestock production and indirect N_2O and CO_2 emissions associated with ammonia volatilization, run-off, and nitrate leaching.

Fossil-based systems are assumed to be net contributors of CO_2 emissions, contrary to bio-based systems where CO_2 circulates between the biological system and the anthroposphere, not contributing to increased concentration of CO_2 in the atmosphere.

Biogenic CO_2 is defined as CO_2 released to the atmosphere due to decomposition and combustion of biological material. Traditionally, biomass-based products have in LCA been considered climate neutral because the biomass that has taken up CO_2 during its growth, is released when the material is combusted or decomposed. The same principle is followed in this study.

Land use (LU) and land use change (LUC) is especially important for agricultural and forestry products. When the amount of biomass above and below ground in an area changes due to changes in land use, this will lead to increased emissions or uptake of CO_2. If an area were initially forest, a transition to agricultural land would lead to increased CO_2 emissions, since forests contain more carbon above and below ground than agricultural land. Such a change of land area is named land transformation or land use change, i.e. the change in the purpose for which land is used by humans (e.g. crop land, grass land, forest land, wetland, industrial land) (BSI, 2011). According to IPCC (2006) and LCA standards and guidelines (ISO 14067, PEFCR and PAS 2050) land use change shall not be accounted for when there has been no change over the last 20 years. If there has been deforestation over the last 20 years, these CO_2 emissions shall be distributed evenly over 20 years. These principles are followed in this study.

2.5.2 Land occupation

Land occupation is a compilation of the number of square meters needed to produce the functional unit. It is divided into different land categories: arable land for concentrate production, imported and domestic, area for grass silage, grazing on arable land, grazing on permanent pasture and outfields.

2.5.3 Biodiversity

Impacts on the biodiversity was assessed for the total area based on the biodiversity damage potential method by Knudsen et al. (2017), using plant species richness compared to natural conditions (i.e., forest with no management or cultivation). The characterization factors in Knudsen et al. (2017) uses the potential disappeared fraction (PDF) of plant species in different land areas used for agriculture. In this study, the PDF values per m2 for a conventional production system according to Knudsen et al. (2019) were used (Table 1) .

A negative value of the PDF indicates a higher plant species diversity than in the semi-natural woodland, which is the reference situation that all land management options compare to.

Table 1 Characterisation factors by Knudsen et al., (2019) used for assessing the impacts on biodiversity of milk and egg production by calculating the potential disappeared fraction (PDF) of plant species in different land areas.

Land management situation	Characterisations factors
Arable land, concentrate ingredients	0.68
Grass silage	0.12
Grazing, arable land	0.09
Grazing, permanent pasture	-0.23
Grazing, outfields	-0.23

2.5.4 Eutrophication

Anthropogenic eutrophication is due to emissions of nutrients such as phosphorus (P) and nitrogen (N). Eutrophication can affect freshwater, marine and terrestrial systems and may be due to a wide variety of polluting inputs including sewage, industrial wastewater, and fertilizer from farming practices. Eutrophication gives a large plant production, unclear water, and algal blooms. Marine eutrophication is measured in kg N eqv. and fresh water is measured in kg P eqv., both methods are based on Struijs et al. (2009). Terrestrial eutrophication is measured in moles N eqv. and is based on Seppälä et al. (2006) and Posch et al. (2008).

2.5.5 Particulate matter

This category is also called "respiratory inorganics" and is an expression of the impact of the emissions on human health. Inorganic particles are measured in "Disease Incidence". The method is based on Fantke et al (2016). Research has shown that the inhalation of particles affects human health. In addition to unspecified particles designated with "PM", the method includes aerosol particles from sulphur and ammonia. The method also includes emissions of nitrogen dioxides, which is a gas that can cause respiratory diseases in local environments.

2.5.6 Acidification

Acidification occurs, among other things, because of long -range air pollution, acid rainfall and emissions of ammonia from, among other things, agriculture. Sour rainfall dissolves important nutrients, such as calcium and potassium, and therefore reduces the availability of plants. It can also cause microorganisms to disappear, and this results in reduced degradation of organic matter. Sour rainfall can dissolve toxic metals, so that, for example, aluminium and mercury are made available to plants and microorganisms. The method is based on Seppälä et al. (2006) and Posch et al. (2008) and are measured in mole H^+ equivalents.

2.5.7 Water use

Water use involves human use of water that is not immediately released back into the same watershed in nature, with the result that the surroundings are deprived of water. Water is an extremely scarce resource in some regions of the world, while water supplies are plentiful in other regions. This means that the environmental impact caused by water use can be very different depending on the region in question. The AWARE method used here therefore adjusts absolute water use with regionalized factors and it quantifies

Available WAter REmaining per unit area. The characterization factors vary between 0.1 and 100 and are measured in m^3 world equivalent. A value of 1 is corresponding to the world average, and a value of 10, for example, representing a region where there is 10 times less available water remaining per area than the world average The method is based on Boulay et al. (2016).

2.6 Data

The livestock production was based on typical production of beef from dairy cattle, beef from beef cattle, mutton and lamb, pork, chicken, turkey, and egg production levels of 2021, using data from herd recording systems available through annual statistics (Animalia, 2021a, 2021b; Animalia et al., 2022; TINE, 2021). See Appendix A1.1-A1.7 for details. During housing, the manure management system considered for each livestock species and animal category (i.e., dairy cow, beef cow, heifer, young bull, etc.) was based on a manure management survey (Kolle & Oguz-Alper, 2020).

For dairy beef and beef cattle, energy requirements and diet composition was obtained using the Nordic feed evaluation system NorFor (Volden, 2011) through TINE Optifor. For sheep, the feeding advisory tool Nortura sauefôring (Nortura, n.d.) and Rekdal & Angeloff (2021) was used for estimating energy requirements and diet composition during housing and feed intake during outfield pasture grazing. For monogastric (i.e. pig, turkey, chicken, and laying hen), feed intake was based on data from Ingris (2021) and Kjøttets tilstand (Animalia et al., 2022). The composition of a typical concentrate feed for dairy cows, heifers, bulls, and pigs was provided by Felleskjøpet Fôrutvikling, and for slaughter pigs, 10% by-products was considered (Bonesmo & Enger, 2021).

Soybeans are often associated with discussion about Land Use Changes (LUC) from forest to agricultural land. Soya imported by Denofa has since 2008 been documented deforestation-free (Proterra certification). An LCA report for Amaggi's production, which has been prepared by an external organization including critical review (Cherubini, 2020), provides an overview of the proportion of land use of land use 20 years back in time based on satellite pictures. Specific data for emissions of CO_2 from LUC for the state of Mato Grosso is provided in Novaes et al. (2017). The proportion of land changed (0,57%) and the emissions per hectare (12,23 ton CO_2 eqv. per hectare) including processing at Denofa give 0.92 kg CO_2 eqv. per kg soybean meal, of this 0,053 kg CO_2 eqv. from LUC, which is used in this assignment as specific data for Denofa and Amaggi. Because the proportion of area where changes have been made in the last 20 years is very small, the calculated specific figures for Denofas soybean meal are lower than is often the case in databases.

2.7 Additional climate models

In this study, LCA is used as a method for a livestock system to assess environmental impacts of meat and egg, and we also want to briefly describe other models and systems that are used. Norway's reporting of greenhouse gas (GHG) emissions[1] includes emissions that occur in Norway and is used to document whether Norway meets its obligations in the climate agreements. The results from the national GHG reporting system are thus based on other system boundaries than an LCA.

Both LCA and national GHG reporting, use characterisation factors for greenhouse gas emissions. The different GHG, e.g. carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are traditionally weighted

---

[1] National Inventory Report to the UNFCCC (United Nations Framework Convention on Climate Change)

together using Global Warming Potential (GWP100) in a time horizon of 100 years (IPCC, 2006, 2013, 2021). The GHG characterisation factors are updated from IPPC as knowledge develops and which factors are used can affect the results (see also section 2.5.1).

2.7.1 GWP* metric

In recent years, the GWP* metric have been suggested by e.g. Allen et al. (2018) as it better accounts for the temperature impact of short-lived climate pollutants, such as CH_4. However, GWP* have been criticized for being a climate model, not a metric (Meinshausen & Nicholls, 2022) and for being sensitive to historical emissions of short-lived climate pollutants (Rogelj & Schleussner, 2019; Schleussner et al., 2019). Using the GWP* methodology is not straight forward and require a time series to be applied. Thus, for the purpose of estimating the climate change of a product, rather than a change in emissions from year 0 to year X, the current GWP* methodology cannot be applied.

2.7.2 Soil carbon balance

Several models exist for estimating soil carbon balance, such as the Introductory Carbon Balance Model (ICBM); (Andrén & Kätterer, 1997; Andrén et al., 2004), which have been calibrated for arable land. Previous studies of cattle production in Norway have shown variable results for carbon sequestration or loss (Figure 3), and (Samsonstuen et al., 2020) pointed out that the current model is sensitive to high initial soil carbon content and should be calibrated to improve future estimations. Although several initiatives (e.g. the C-Sequ project) have been made to develop a common methodology for including soil carbon balance in LCA, the recommendation remain to report sequestration (or loss) separately to the carbon footprint results due to limiting data availability and uncertainty (International Dairy Federation, 2022). Thus, soil carbon balance is not included in the assessment in this report, which is in alignment with ISO 14067, PEFCR for dairy products (European Dairy Association, 2018) and PEFCR for feed (FEFAC, 2018). However, calibration of the ICBM model for permanent grassland and outfield pasture based on soil samples from Norwegian pastures are currently done in the project SUSCOW, and soil carbon balance from permanent and outfield pastures might be possible to include in the future.

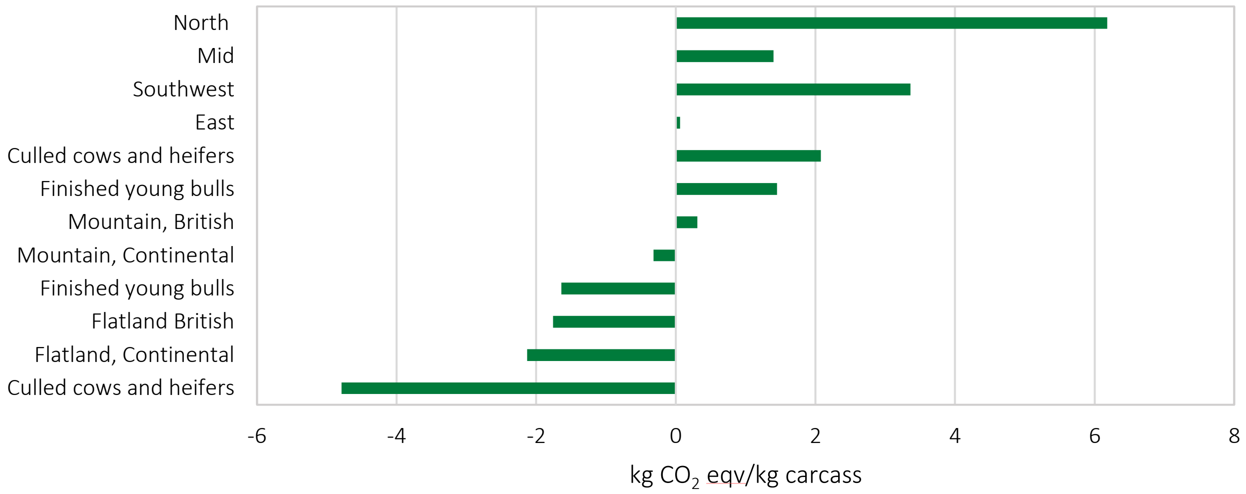

Figure 3 Carbon sequestration or carbon loss associated with beef production in Norway, measured in kg of carbon dioxide equivalents per kg of carcass weight. Negative values mean sequestration (removal of C from the air) and positive values means carbon loss (emissions of C to the air). Values are averages. Based on Bonesmo et al. (2013), Samsonstuen et al. (2019) and Samsonstuen et al. (2020).

3 Results

3.1 Beef from dairy cattle

The total environmental impacts per kg carcass of dairy cattle, including heifers and bulls, are provided in Table 2. Detailed results for each environmental impact throughout the life cycle up to slaughterhouse gate, are shown in the following figures.

Table 2 Total environmental impacts per kg carcass of dairy cattle at the slaughterhouse gate.

Impact category and unit	**Impact per kg of carcass**
GHG total (kg CO_2 eqv)	21.6
GHG biogenic (kg CO_2 eqv)	10.2
GHG fossil (kg CO_2 eqv)	11.0
GHG LULUC (kg CO_2 eqv)	0.5
Land occupation, excl. outfields (m^2)	27
Biodiversity (PDF)	7.0
Eutrophication, marine (kg N eqv)	0.05
Eutrophication, freshwater (kg P eqv)	0.014
Eutrophication, terrestrial (mol N eqv)	1.9
Particulate matter (disease inc.)	2.7E-06
Acidification (mol H+ eqv)	0.41
Water use[2] (m3 depriv.)	1.8

---

[2] Deprivation-weighted water use

3.1.1 Climate change

The GHG emissions from dairy cattle is shown in Figure 4. Most of the emissions occur on the farm. Enteric methane is the largest single emission and accounts for approximately 40% of total GHG emissions. Methane from manure storage is approx. 6% of total GHG emissions.

Emissions of nitrous oxide (N_2O) occur both from the storage of manure (12%) and spreading of manure and mineral fertiliser (20%). The latter is in Figure 4 shown under domestic feed, which consists of forage and feed concentrate. Other emissions from domestic feed production are CO_2 (12%) which results from the use of fuel for tillage and harvesting. Only a small part of GHG emissions from imported feed is from LUC, as mentioned in section 2.6, this is based on data for soybean meal from Denofa's production. Emissions from the slaughterhouse are from energy use and is less than 1% of total GHG emissions. Other greenhouse gases are from processes related to input factors.

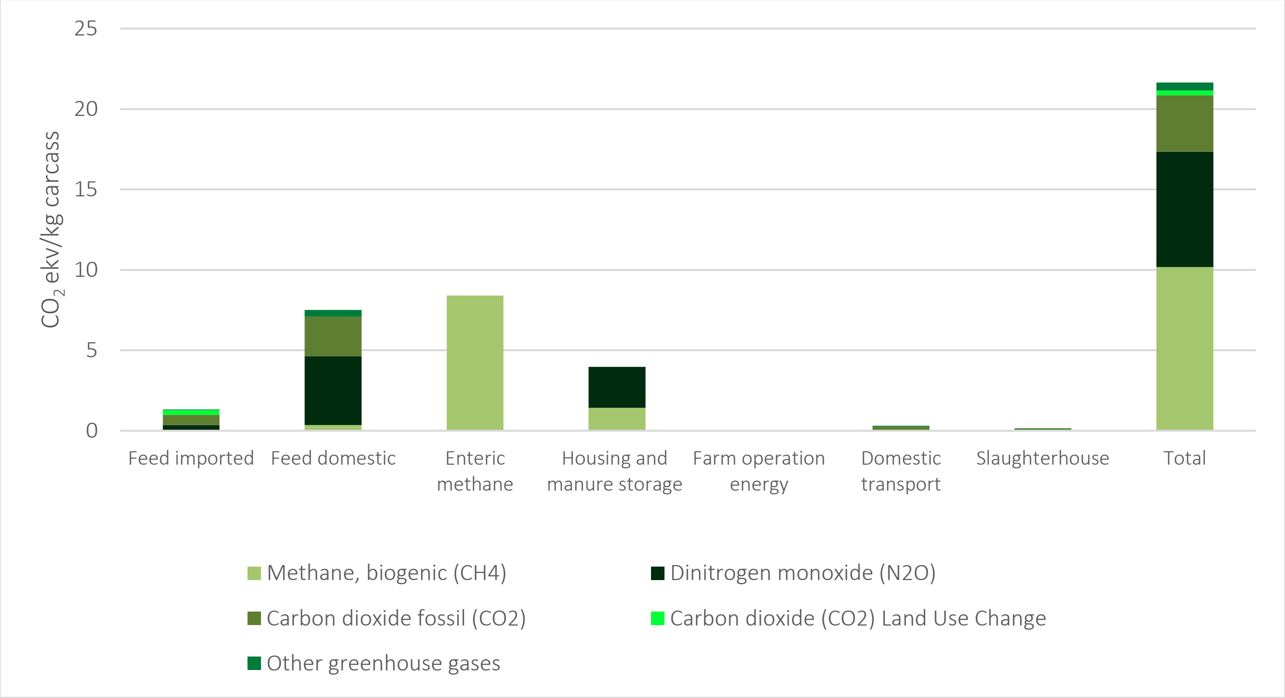

Figure 4 Climate change (CO_2 eqv.) per kg carcass through the life cycle (cradle to the gate of the slaughterhouse) of beef from dairy cattle

3.1.2 Land occupation

Land occupation for production of feed is shown in Figure 5, other land occupation is not mapped in this study. The figure shows the total area on the right side of the figure and distributed for each land category on the left side. The main contribution to land occupation is grass silage production, which takes up more than 40% of the total area, followed by grain production used in feed concentrate (28%).

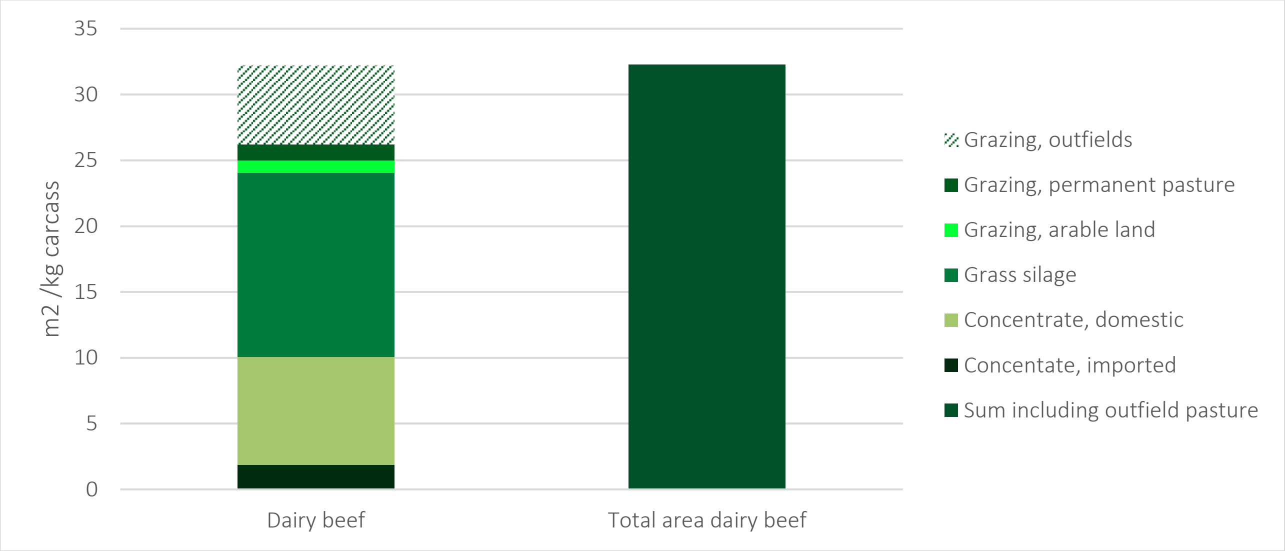

Figure 5 Land occupation (m^2) distributed by land category per kg carcass of dairy cattle through the life cycle (cradle to the gate of the slaughterhouse).

3.1.3 Biodiversity

Loss of biodiversity linked to land for feed production is shown in Figure 6, as potentially disappeared fraction (PDF). The method and characterization factor used for each land category is described in section 2.5.3 Negative values in the figure, as for outfields, implies that there is higher plant species richness than in the reference of semi-natural woodlands. The column on the right in figure shows the net loss of biodiversity as PDF.

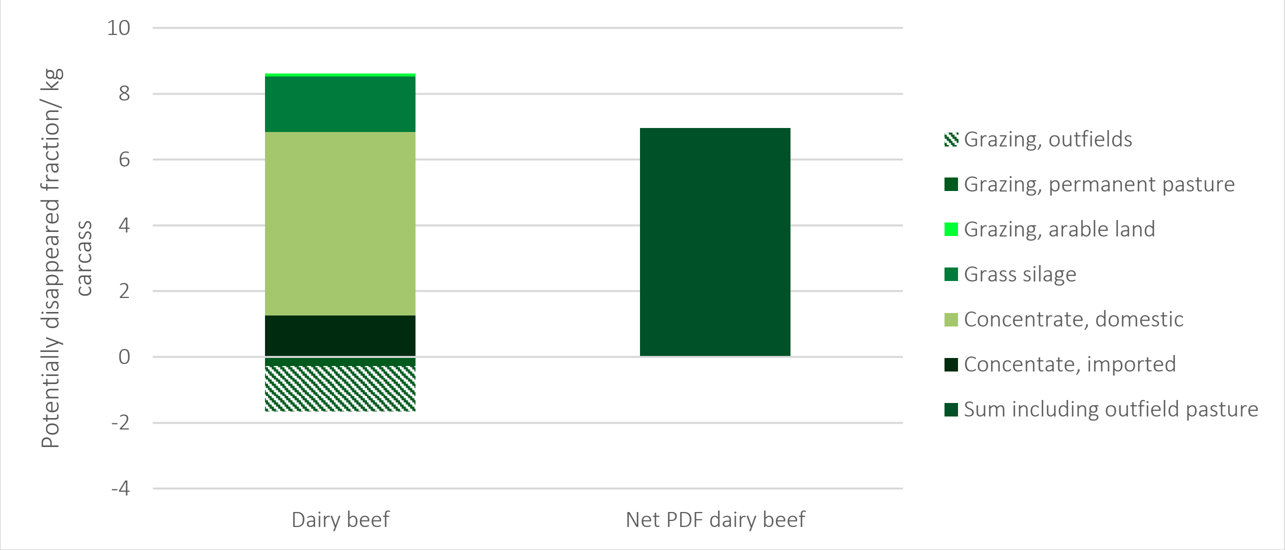

Figure 6 Biodiversity as potential disappeared fraction (PDF; Knudsen et al., 2017) per kg carcass of dairy cattle.

3.1.4 Eutrophication

Eutrophication for freshwater (P eqv.), marine (N eqv.) and terrestrial (moles N eqv.) systems occurs due to emissions of nitrogen and phosphorus compounds, see further description of the method in section 2.5.4 Figure 7 shows the impact from each life cycle step as percentage of total impact for each category. The figure shows that most emissions are linked to domestic feed production for all eutrophication categories. For marine eutrophication 30% of the emissions is due to feed imports, 59% from domestic feed production, and 9% from housing and manure storage. For terrestrial eutrophication 58% of the impact occurs from emissions from domestic feed production and 36% from housing and manure storage.

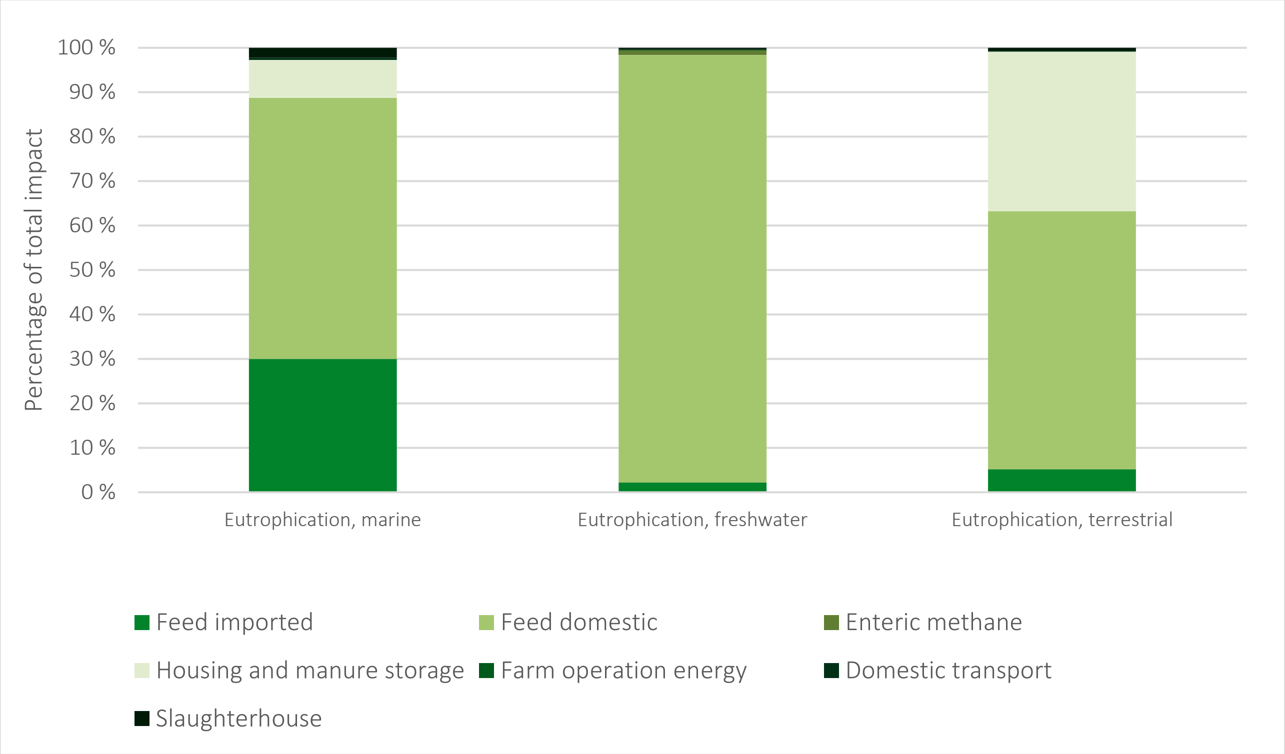

Figure 7 Marine eutrophication, freshwater eutrophication and terrestrial eutrophication per kg carcass of dairy cattle through the life cycle (cradle to the gate of the slaughterhouse) as percentage of total impact for each category.

3.1.5 Particulate matter

Particulate matter is an expression of the impact of the emissions of respiratory inorganics on human health and is measured in "Disease Incidence", see section 2.5.5 Figure 8 shows the impacts throughout the life cycle and it can be seen that the largest emissions occur in domestic feed production (55%) and housing and manure storage (38%). The impacts to particulate matter are mainly from emissions of ammonia and nitrogen dioxide.

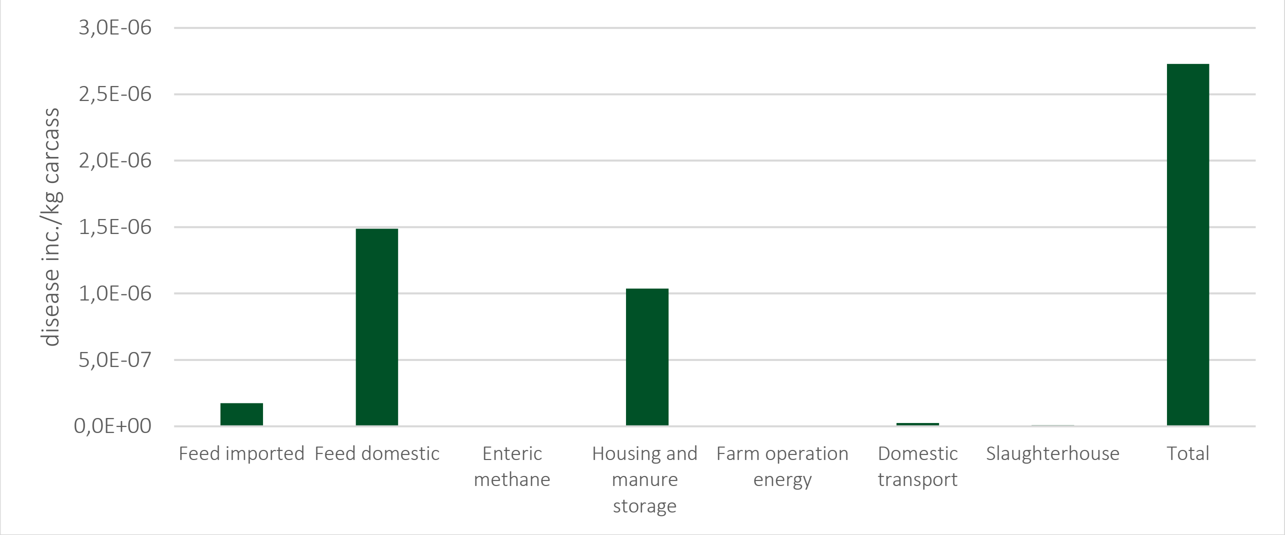

Figure 8 Particulate matter (disease inc.) per kg carcass of dairy cattle through the life cycle (cradle to the gate of the slaughterhouse).

3.1.6 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 9, and therefore the impact from acidification is quite similar to that from particulate matter (section 3.1.5 as it is the same type of emissions, but which potentially cause different environmental impacts. The largest emissions occur in domestic feed production (57%) and housing and manure storage (36%).

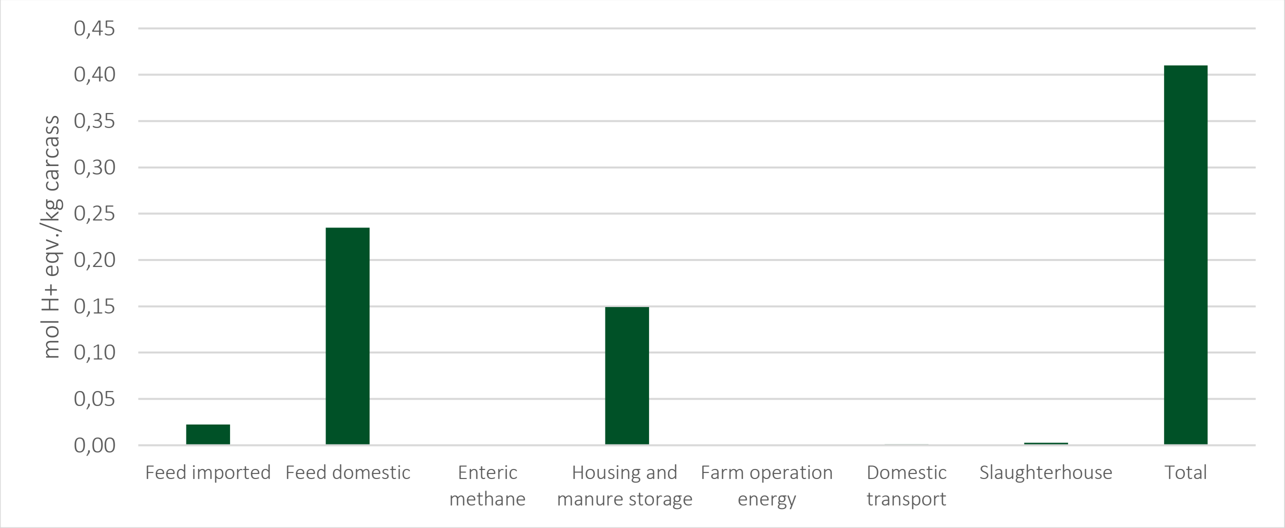

Figure 9 Acidification (mol H^+ eqv.) per kg carcass of dairy cattle through the life cycle (cradle to the gate of the slaughterhouse).

3.1.7 Water use

Water is an extremely scarce resource in some regions of the world, while water supplies are plentiful in other regions. The AWARE method used here therefore adjusts absolute water use with regionalized factors and it quantifies Available WAter REmaining per unit area. The characterization factors vary between 0.1 and 100 and are measured in m^3 world equivalent.

Figure 10 shows that the imported feed has the largest water use (62%), followed by domestic feed (28%) and slaughterhouse (6%). The imported feed has a high water use because the characterisation factor for water is much higher in many other countries than in Norway. The imported feed consists of concentrated feed and water is used, e.g. for irrigation, pesticide dilution, and urea production. The water use for domestic feed mainly occurs in the production of machinery, fertiliser, diesel, and bale wrap for grass silage, i.e. it is not the feed production itself but in the upstream value chain. The same applies to water consumption for the slaughterhouse, where the largest part of water consumption is linked to the production of energy and materials.

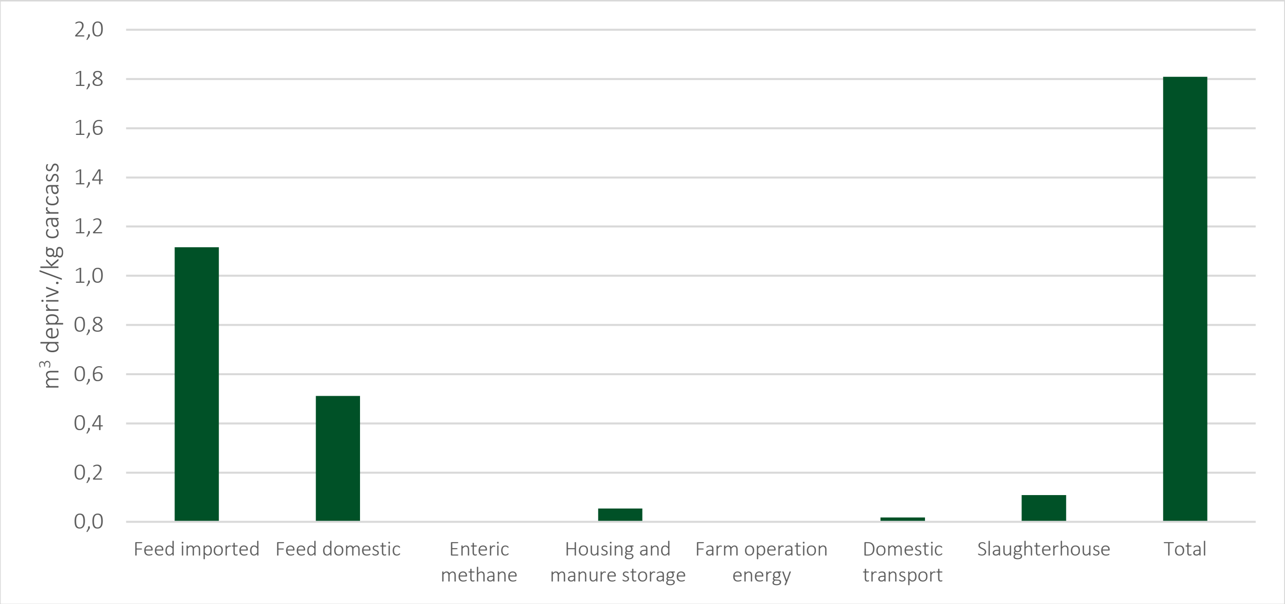

Figure 10 Water use (m^3 depriv.) per kg carcass of beef from dairy cattle through the life cycle (cradle to slaughterhouse gate).

3.2 Beef from beef cattle

The total environmental impacts per kg carcass of beef cattle are provided in Table 3. Detailed results for each environmental impact throughout the life cycle up to slaughterhouse gate, are shown in the following figures.

Table 3 Total environmental impacts per kg beef carcass from beef cattle at the slaughterhouse gate.

Impact category and unit	Impact per kg of carcass
GHG total (kg CO_2 eqv)	30.0
GHG biogenic (kg CO_2 eqv)	16.3
GHG fossil (kg CO_2 eqv)	13.6
GHG LULUC (kg CO_2 eqv)	0.1
Land occupation, excl. outfields (m^2)	28
Biodiversity (PDF)	-13.7
Eutrophication, marine (kg N eqv)	0.04
Eutrophication, freshwater (kg P eqv)	0.011
Eutrophication, terrestrial (mol N eqv)	2.5
Particulate matter (disease inc.)	3.8E-06
Acidification (mol H+ eqv)	0.56
Water use[3] (m3 depriv.)	0.58

---

[3] Deprivation-weighted water use

3.2.1 Climate change

The GHG emissions from beef cattle is shown in Figure 11. Most of the emissions occur on the farm. Enteric methane is the largest single emission and accounts for approximately 50% of total GHG emissions. Methane from manure storage is about 5% of total GHG emissions.

Emissions of nitrous oxide (N_2O) occur both from the storage of manure (14%) and spreading of manure and mineral fertiliser (20%). The latter is in Figure 11 shown under domestic feed, which consists of forage and feed concentrate. Other emissions from domestic feed production are CO_2 (7%) which results from the use of fuel for tillage and harvesting. Emissions from the slaughterhouse are from energy use and is less than 1% of total GHG emissions. Other greenhouse gases are from processes related to input factors.

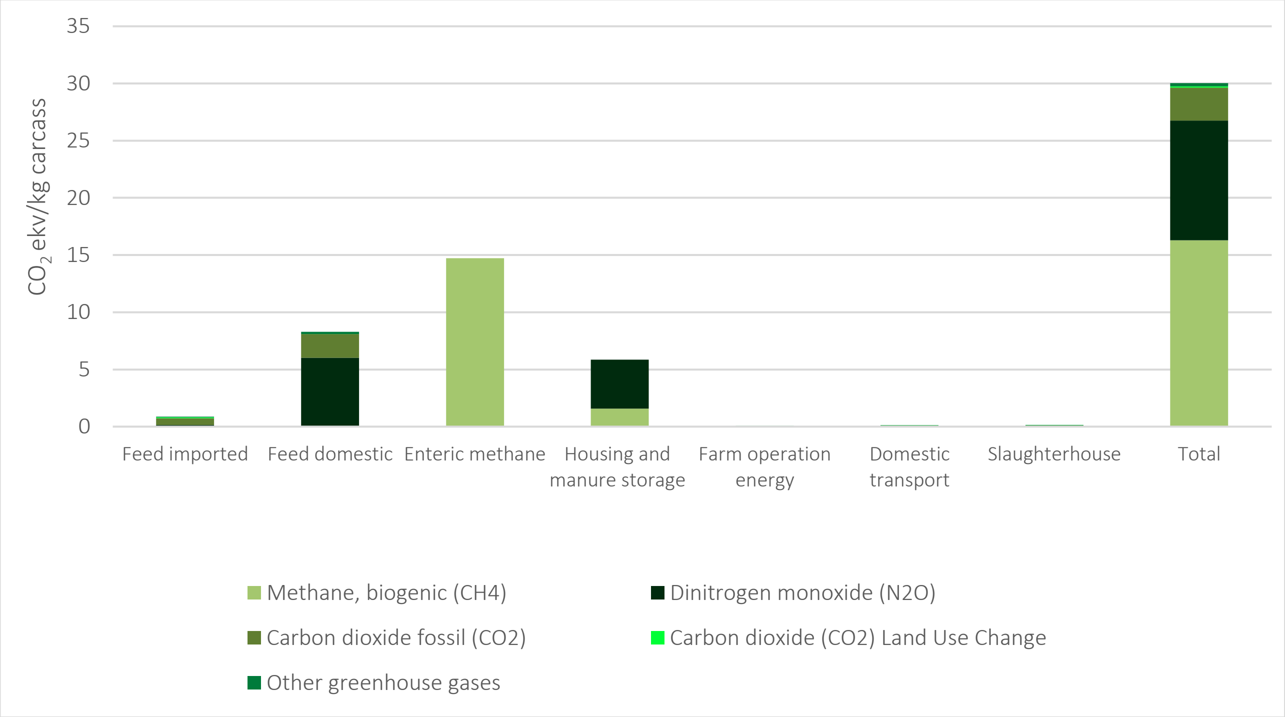

Figure 11 Climate change (CO_2 eqv.) per kg carcass through the life cycle (cradle to the slaughterhouse gate) of beef from beef cattle.

3.2.2 Land occupation

Land occupation for production of feed is shown in Figure 12, other land occupation is not mapped in this study. The figure shows the total area on the right side of the figure and distributed for each land category on the left side. Land for grazing in outfields represents 75% of the total area. This is due to a low yield on this type of pasture. The second largest area is for grass silage amounts to 13% of the total area. Area for grain production used in feed concentrate is 6% of the total area.

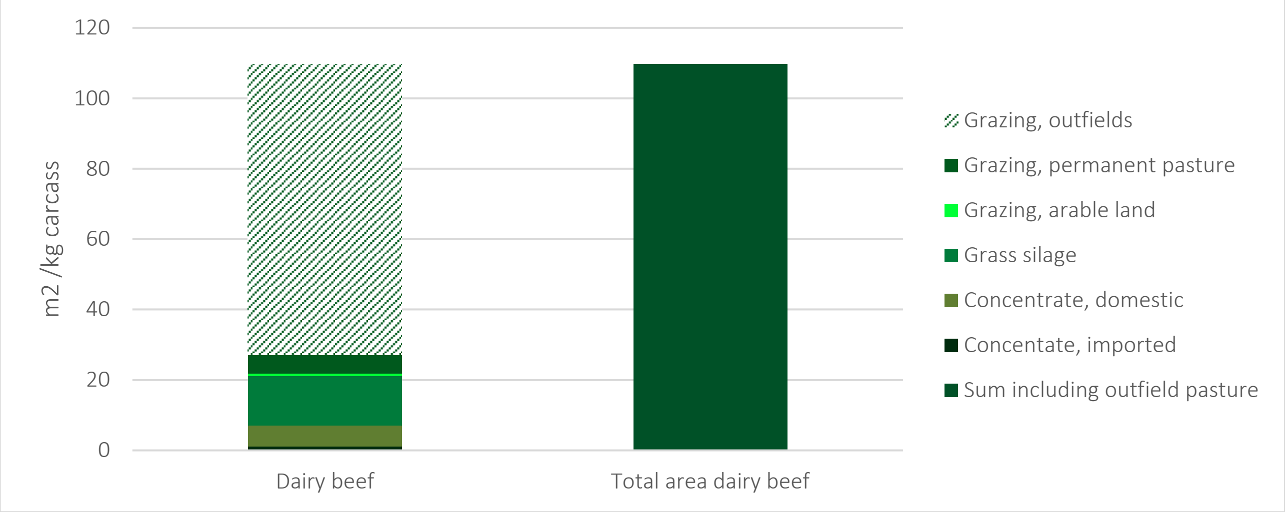

Figure 12 Land occupation (m^2) distributed by land category per kg carcass of beef from beef cattle through the life cycle (cradle to the slaughterhouse gate).

3.2.3 Biodiversity

Loss of biodiversity linked to land for feed production is shown in Figure 13, as potentially disappeared fraction (PDF). The method is described in section 2.5.3 Negative values for outfields imply that grazing in such area results in higher plant species richness than in the reference of semi-natural woodlands. The column on the right in figure shows that beef from beef cattle gives a net negative value, i.e., this production contributes to increased biodiversity.

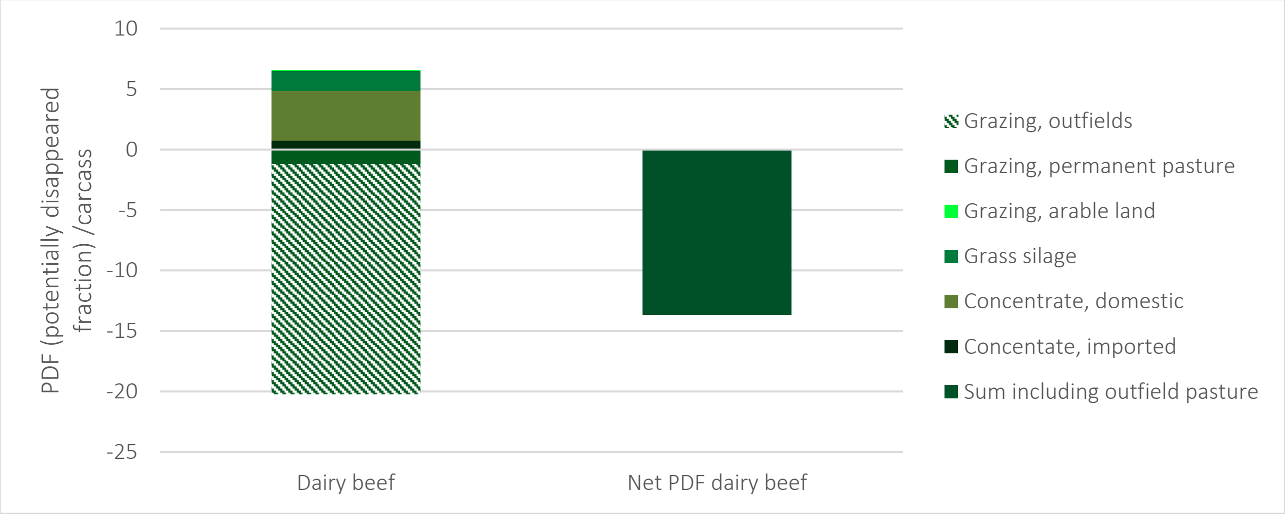

Figure 13 Biodiversity as potential disappeared fraction (PDF; Knudsen et al., 2017) per kg carcass of beef from beef cattle

3.2.4 Eutrophication

Eutrophication for freshwater (P eqv.), marine (N eqv.) and terrestrial (moles N eqv) systems occurs due to emissions of nitrogen and phosphorus compounds, see further description of the method in section 2.5.4 Figure 14 shows the impact from each life cycle step as percentage of total impact for each category. The figure shows that most emissions are linked to domestic feed production for all eutrophication categories. For marine eutrophication 17% of the emissions is due to feed imports, 63% from domestic feed production and 17% from housing and manure storage. For terrestrial eutrophication 59% is from domestic feed production and 39% of the impact occurs from emissions from housing and manure storage.

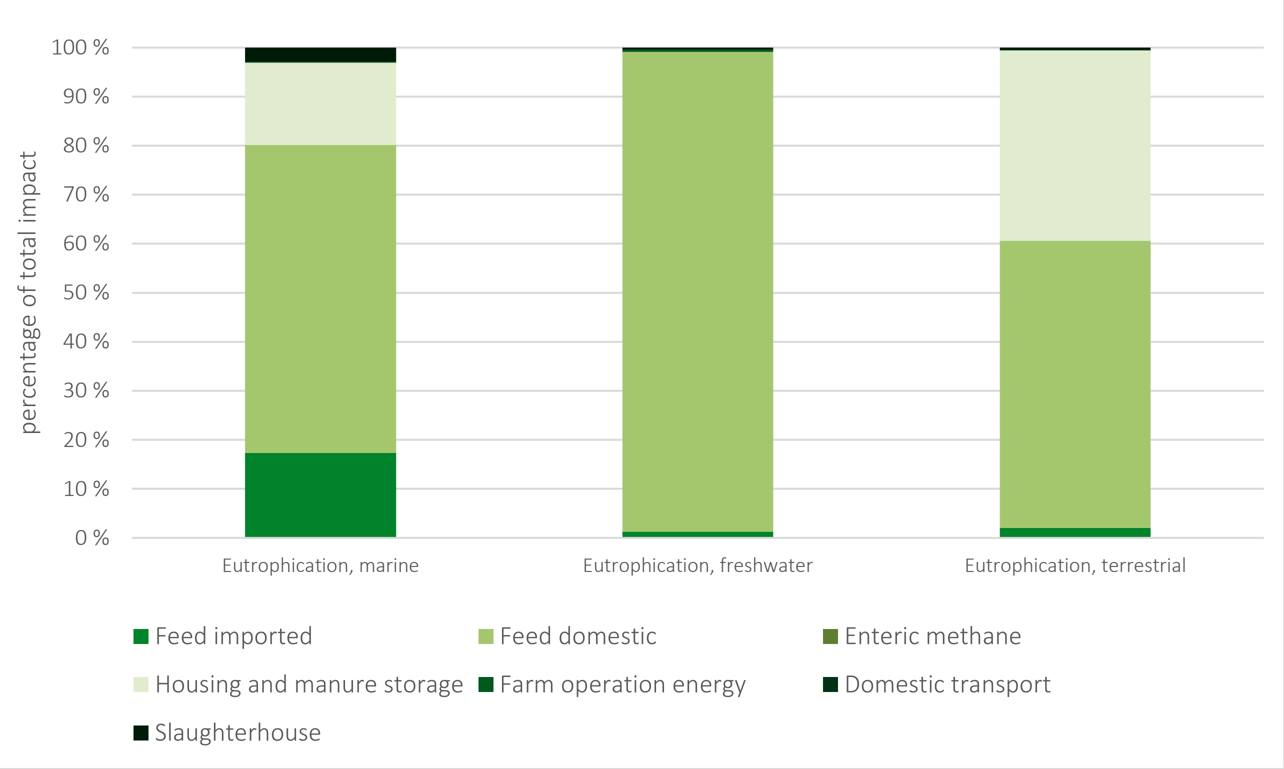

Figure 14 Marine eutrophication, freshwater eutrophication and terrestrial eutrophication per kg carcass of beef from beef cattle through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category.

3.2.5 Particulate matter

Particulate matter is an expression of the impact of the emissions of respiratory inorganics on human health and is measured in "Disease Incidence", see section 2.5.5 Figure 15 shows the impacts throughout the life cycle and the largest emissions occur in domestic feed production (57%) and housing and manure storage (40%). The impacts to particulate matter are mainly from emissions of ammonia and nitrogen dioxide.

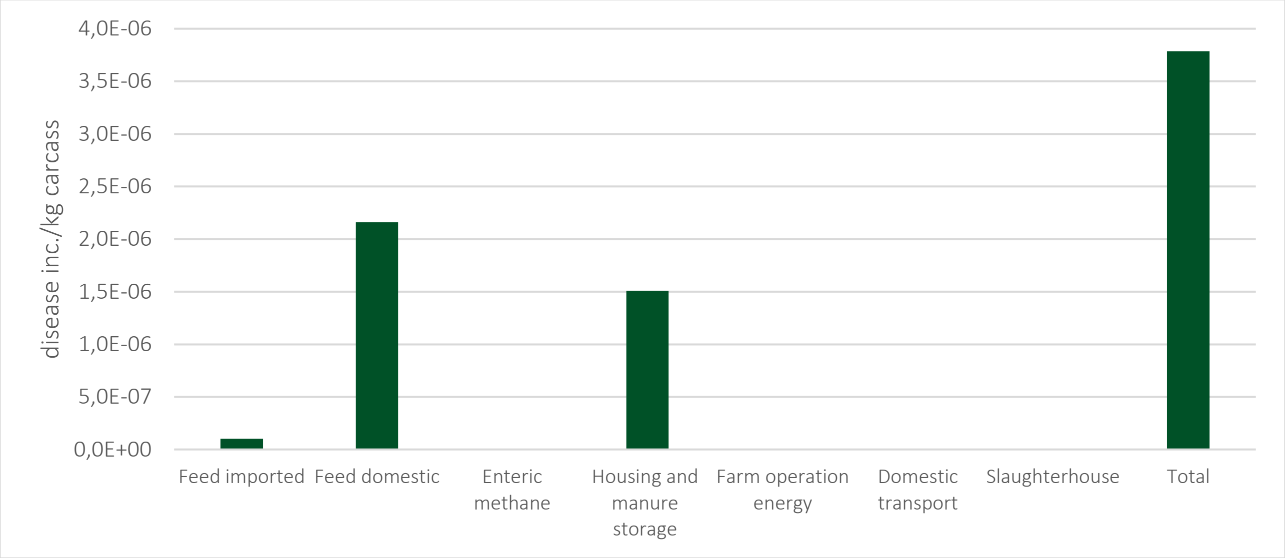

Figure 15 Particulate matter (disease inc.) per kg carcass of beef from beef cattle through the life cycle (cradle to slaughterhouse gate).

3.2.6 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 16, and therefore the impact from acidification is quite similar to that from particulate matter (section 3.1.5 as it is the same type of emissions, but which potentially cause different environmental impacts. The largest emissions occur in domestic feed production (58%) and housing and manure storage (39%).

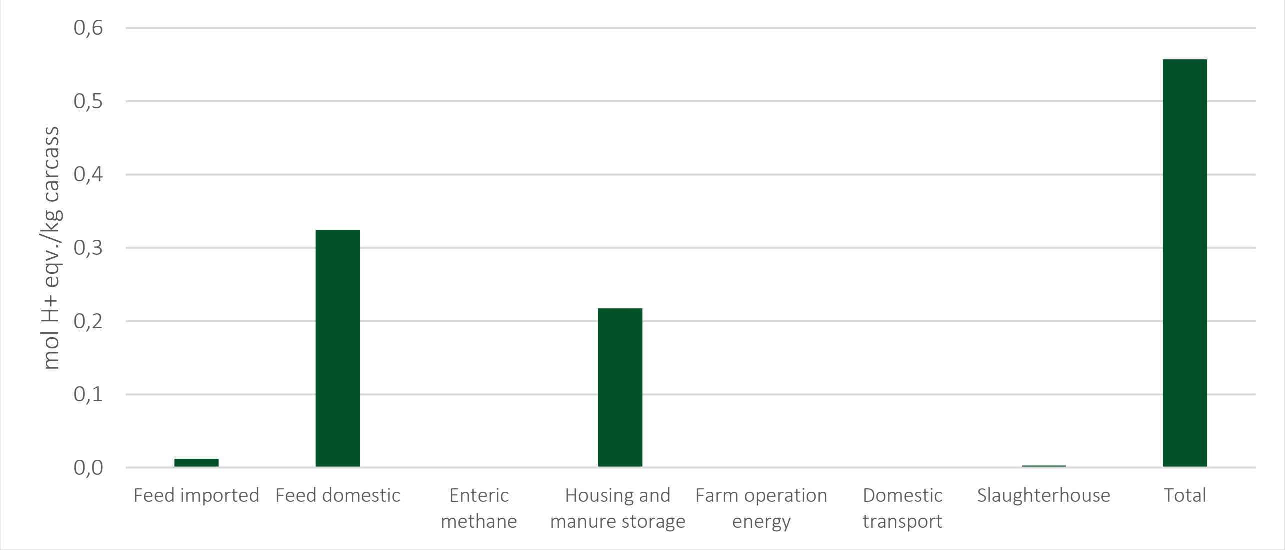

Figure 16 Acidification (mol H^+ eqv.) per kg carcass of beef from beef cattle through the life cycle (cradle to slaughterhouse gate).

3.2.7 Water use

Water is an extremely scarce resource in some regions of the world, while water supplies are plentiful in other regions. The AWARE method used here therefore adjusts absolute water use with regionalized factors and it quantifies Available WAter REmaining per unit area. The characterization factors vary between 0.1 and 100 and are measured in m^3 world equivalent.

Figure 17 shows that the domestic feed imported feed has the largest water use (43%), followed by slaughterhouse (19%), feed imported (15%), and housing (15%). The water use for domestic feed mainly occurs in the production of machinery, fertiliser, diesel, and bale wrap for grass silage, i.e. it is not the feed production itself but in the upstream value chain. The same applies to water consumption for the slaughterhouse, where the largest part of water consumption is linked to the production of energy and materials. The imported feed consists of concentrated feed and water is used, e.g. for irrigation, pesticide dilution, and urea production. Water use in housing is drinking water for the livestock.

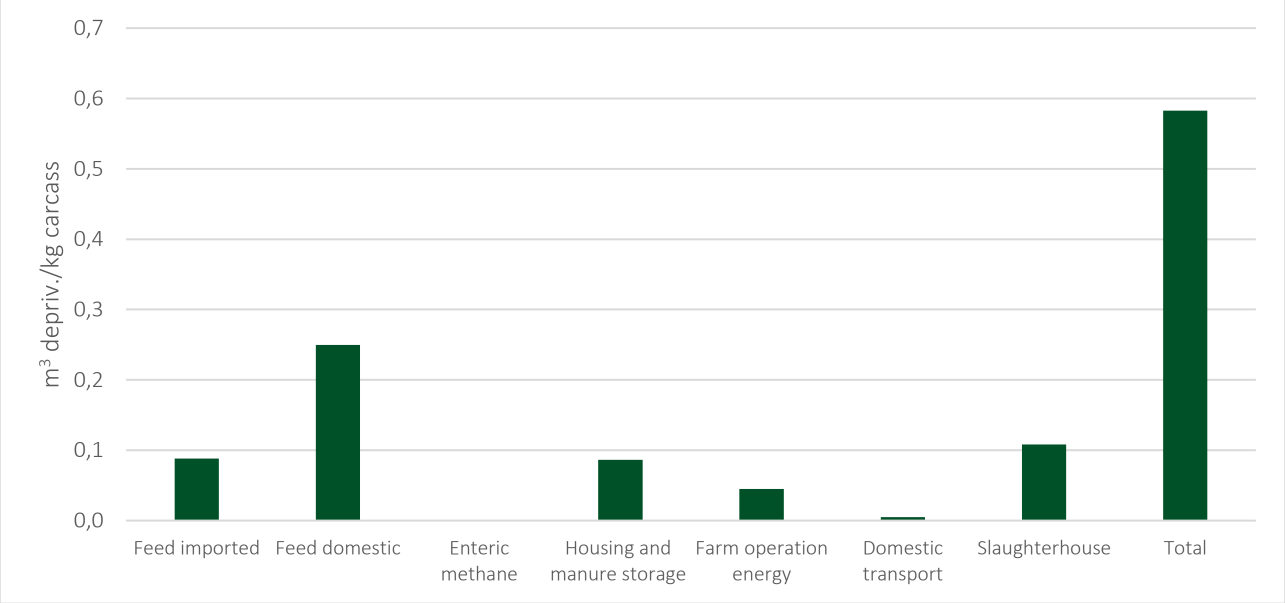

Figure 17 Water use (m^3 depriv.) per kg carcass of beef from beef cattle through the life cycle (cradle to slaughterhouse gate).

3.3 Mutton and lamb

The total environmental impacts per kg carcass of sheep and lamb are provided in Table 4. Detailed results for each environmental impact throughout the life cycle are shown in the following figures.

Table 4 Total environmental impacts per kg carcass of sheep and lamb at the slaughterhouse gate.

Impact category and unit	Impact per kg of carcass
GHG total (kg CO_2 eqv)	26.1
GHG biogenic (kg CO_2 eqv)	11.7
GHG fossil (kg CO_2 eqv)	14.3
GHG LULUC (kg CO_2 eqv)	0.1
Land occupation, excl. outfields (m^2)	28
Biodiversity (PDF)	-41
Eutrophication, marine (kg N eqv)	0.06
Eutrophication, freshwater (kg P eqv)	0.011
Eutrophication, terrestrial (mol N eqv)	1.8
Particulate matter (disease inc.)	2.4E-06
Acidification (mol H+ eqv)	0.39
Water use[4] (m3 depriv.)	0.76

---

[4] Deprivation-weighted water use

3.3.1 Climate change

The GHG emissions from sheep and lamb is shown in Figure 18. Most of the emissions occur on the farm. Enteric methane is the largest single emission and accounts for 44% of total GHG emissions. Methane from manure storage is about 1% of total GHG emissions. This share of methane from manure storage is low due to a long grazing period and because the lambs are slaughtered in the autumn and are not fed in the barn. Thus, there is less manure in the manure storage. Emissions from manure deposited on pasture are included in the bar for domestic feed in Figure 18.

Emissions of nitrous oxide (N_2O) occur both from the storage of manure (16%) and spreading of manure and mineral fertiliser (28%). The latter is in Figure 18 shown under domestic feed, which consists of forage and feed concentrate. Other emissions from domestic feed production are CO_2 (8%) which results from the use of fuel for tillage and harvesting. Emissions from the slaughterhouse are from energy use and is less than 1% of total GHG emissions. Other greenhouse gases are from processes related to input factors.

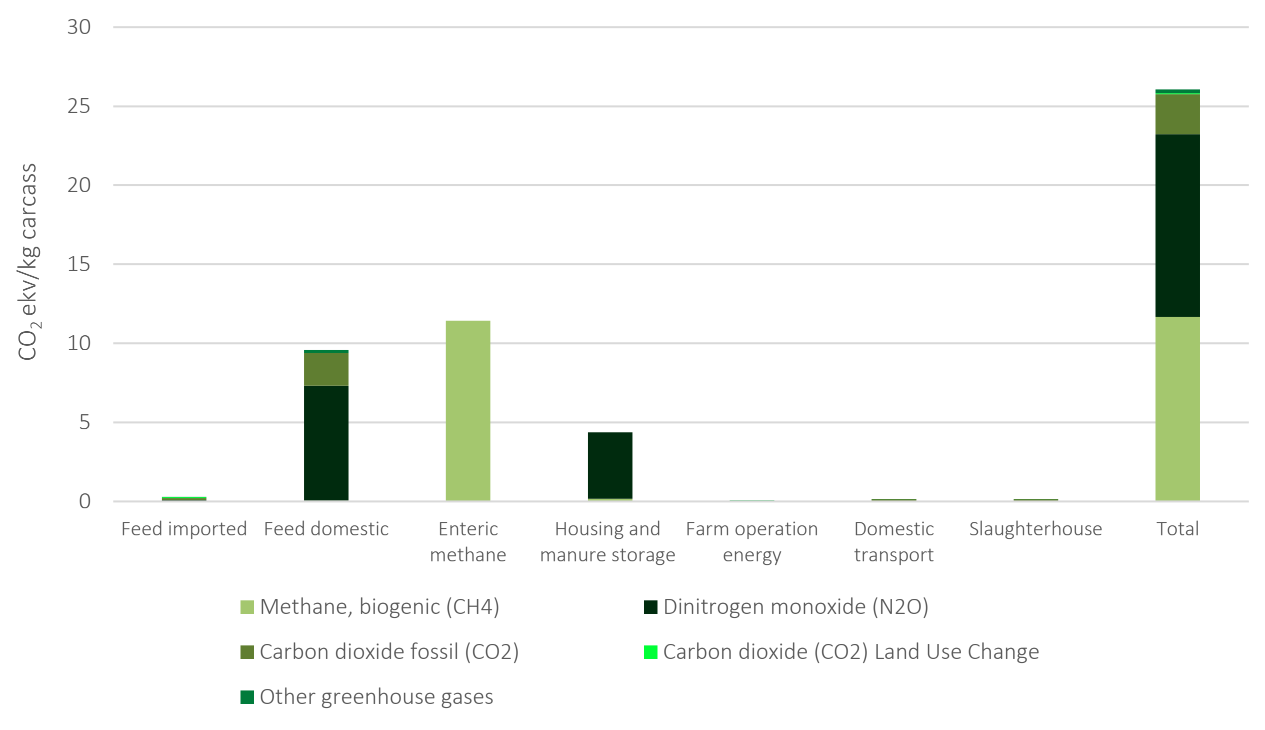

Figure 18 Climate change (CO_2 eqv.) per kg carcass through the life cycle (cradle to slaughterhouse ate) of sheep and lamb.

3.3.2 Land occupation

Land occupation for production of feed is shown in Figure 19, other land occupation is not mapped in this study. The figure shows the total area on the right side of the figure and distributed for each land category on the left side. Land for grazing in outfields accounts for 88% of the total area used for feed production, due to a low yield on this type of pasture. The second largest area is for grass silage which is 6% of the total area. Area for grain production used in feed concentrate is 3% of the total area.

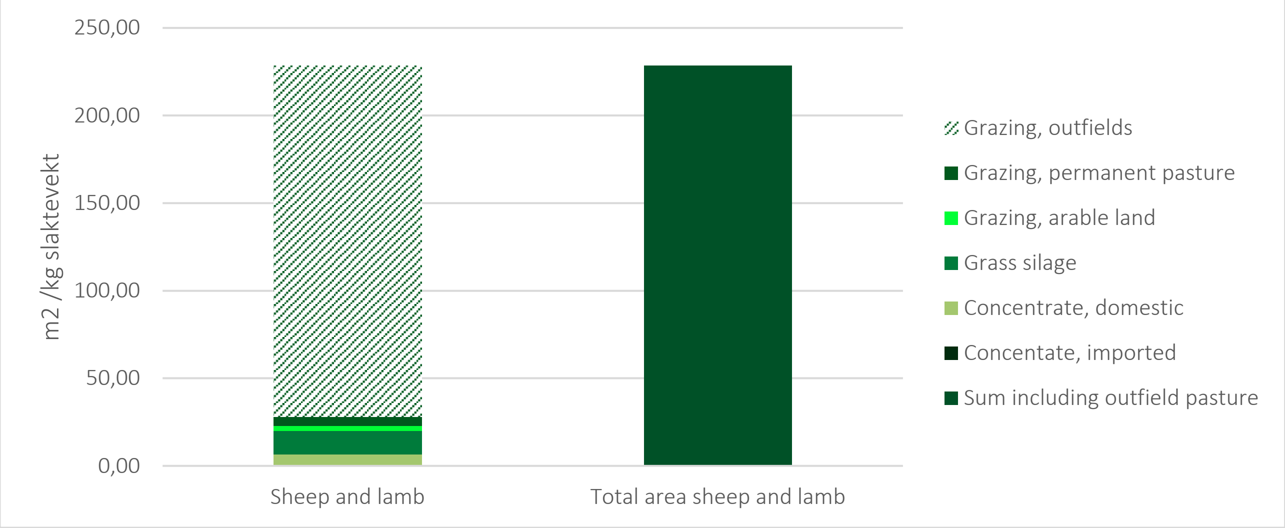

Figure 19 Land occupation (m^2) distributed by land category per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate).

3.3.3 Biodiversity

Loss of biodiversity linked to land for feed production is shown in Figure 20, as potentially disappeared fraction (PDF). The method and characterization factor used for each land category is described in section 2.5.3 Negative values for outfields imply that grazing in such area gives higher plant species richness than in the reference of semi-natural woodlands. The column on the right in figure shows that sheep production gives a net negative value, i.e., this production contributes to increased biodiversity.

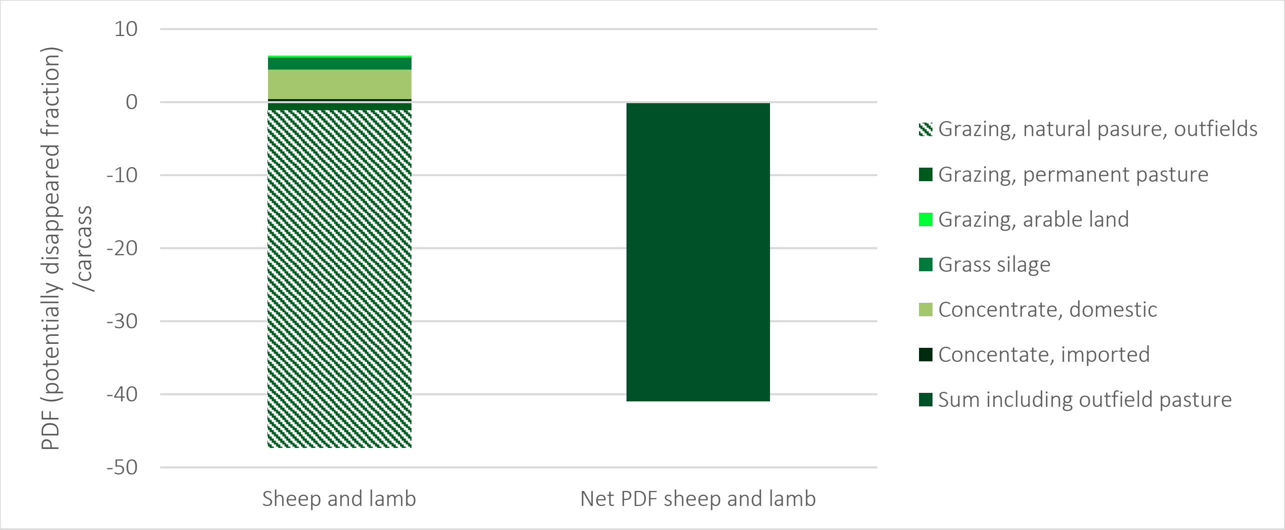

Figure 20 Biodiversity as potential disappeared fraction (PDF; Knudsen et al., 2017) per kg carcass of sheep and lamb

3.3.4 Eutrophication

Eutrophication for freshwater (P eqv.), marine (N eqv.) and terrestrial (moles N eqv.) systems occurs due to emissions of nitrogen and phosphorus compounds, see further description of the method in section 2.5.4 Figure 21 shows the impact from each life cycle step as percentage of total impact for each category. The figure shows that most emissions are linked to domestic feed production for all eutrophication categories. For marine eutrophication 84% of the emissions is due to domestic feed production. For terrestrial eutrophication 68% of the impact is from domestic feed production and 30% of the impact occurs from emissions from housing and manure storage.

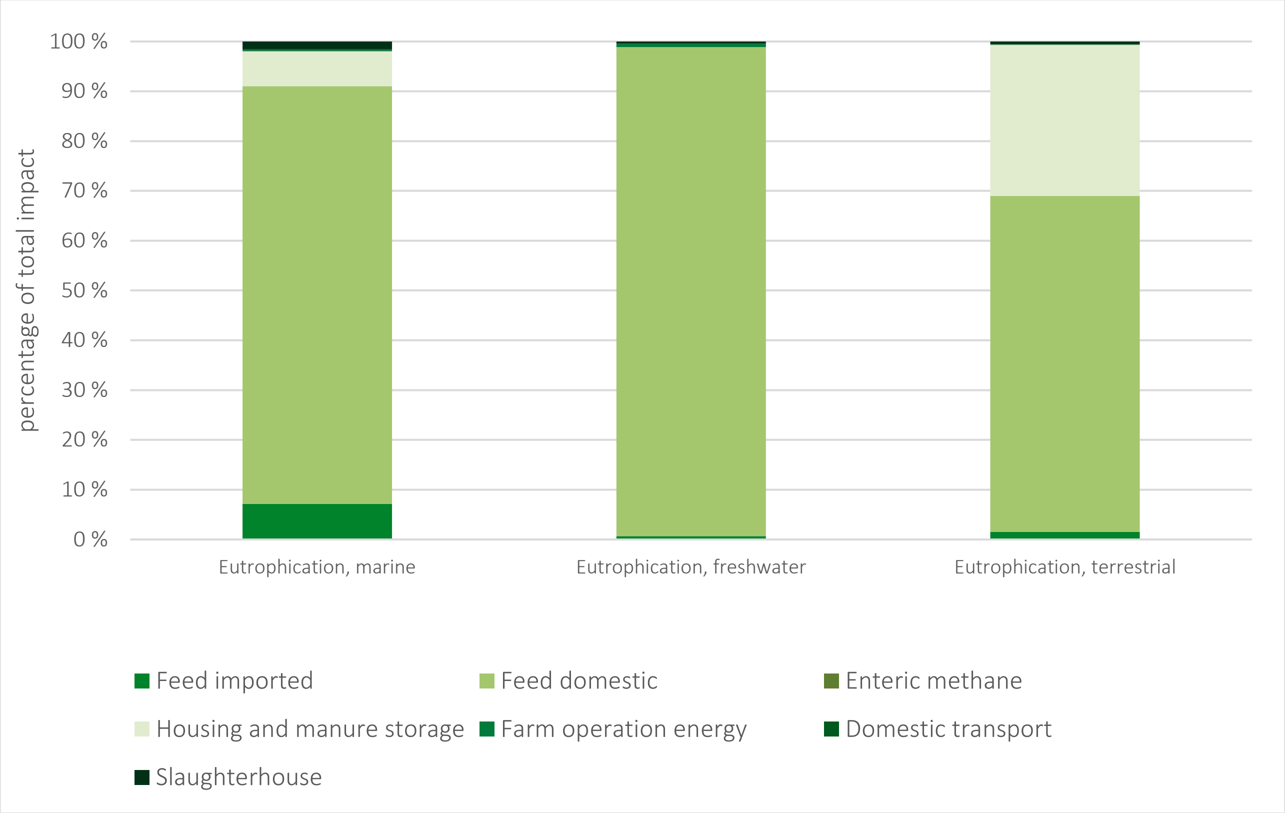

Figure 21 Marine eutrophication, freshwater eutrophication and terrestrial eutrophication per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category

3.3.5 Particulate matter

Particulate matter is an expression of the impact of the emissions of respiratory inorganics on human health and is measured in "Disease Incidence", see section 2.5.5 Figure 22 shows the impacts throughout the life cycle and the largest emissions occur in domestic feed production (62%) and housing and manure storage (36%). The impacts to particulate matter are mainly from emissions of ammonia and nitrogen dioxide.

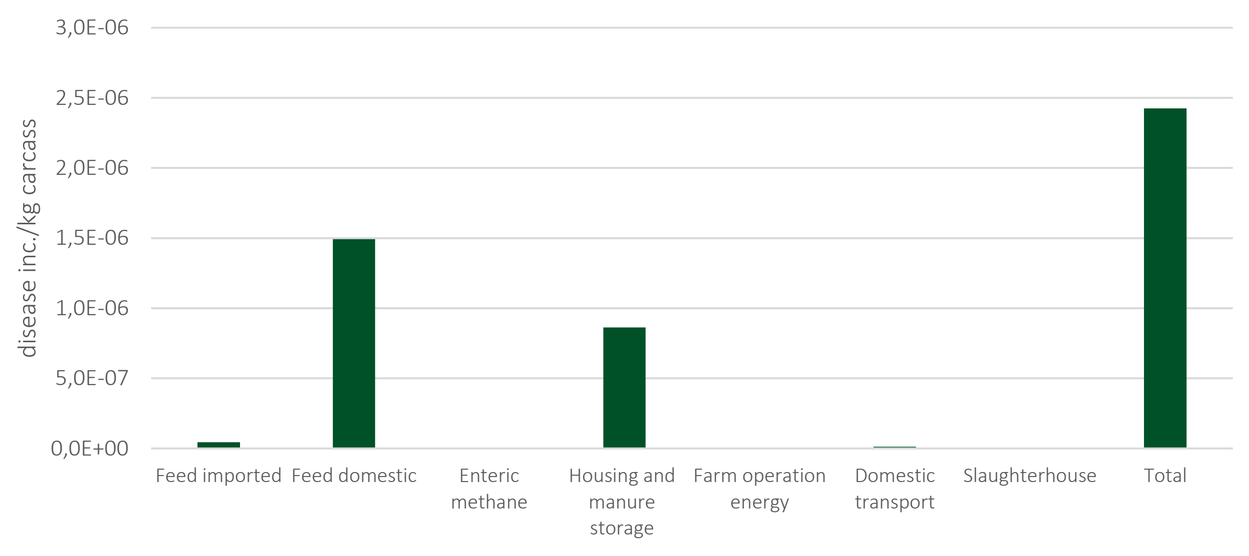

Figure 22 Particulate matter (disease inc.) per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate).

3.3.6 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 23, and therefore the impact from acidification is quite similar to that from particulate matter (section 3.1.5 as it is the same type of emissions, but which potentially cause different environmental impacts. The largest emissions occur in domestic feed production (66%) and housing and manure storage (32%).

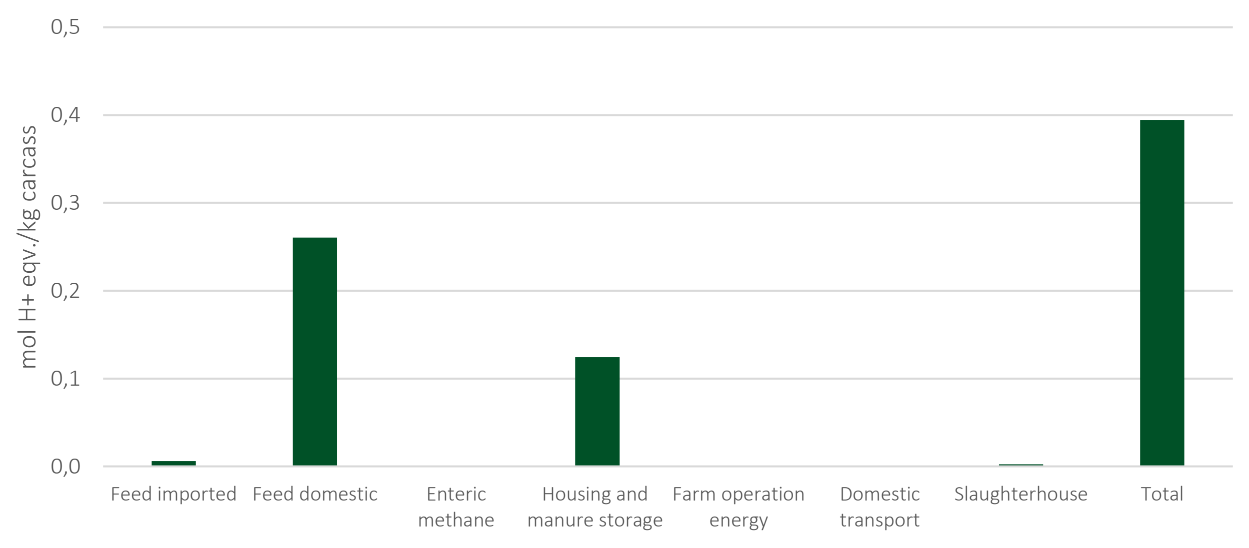

Figure 23 Acidification (mol H^+ eqv.) per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate).

3.3.7 Water use

Water is an extremely scarce resource in some regions of the world, while water supplies are plentiful in other regions. The AWARE method used here therefore adjusts absolute water use with regionalized factors and it quantifies Available WAter REmaining per unit area. The characterization factors vary between 0.1 and 100 and are measured in m^3 world equivalent.

Figure 24 shows that the domestic feed has the largest water consumption (38%), followed by housing (34%), feed imported (19%) and slaughterhouse (7%).

The water use for domestic feed mainly occurs in the production of machinery, fertiliser, diesel, and bale wrap for grass silage, i.e. it is not the feed production itself but in the upstream value chain. The same applies to water consumption for the slaughterhouse, where the largest part of water consumption is linked to the production of energy and materials. Water use in housing is drinking water for the livestock. The imported feed consists of concentrated feed and water is used, e.g. for pesticide dilution and fertiliser.

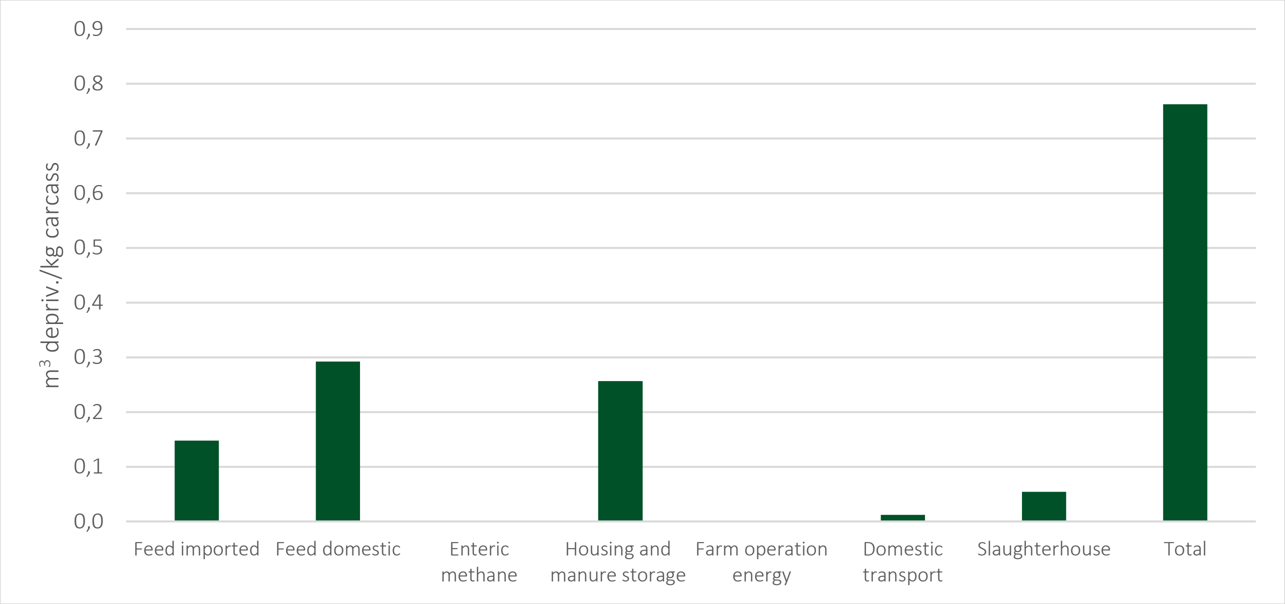

Figure 24 Water use (m^3 depriv.) per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate).

3.4 Pork

The total environmental impacts per kg carcass of pig are provided in Table 5. Detailed results for each environmental impact throughout the life cycle are shown in the following figures.

However, this does not apply to biodiversity as the method used in this study does not distinguish between different crops and uses the same characterisation factors for arable land. Still, the total value for biodiversity is shown in Table 5 to be able to compare between animal species.

Table 5 Total environmental impacts per kg carcass of pig at the gate of the slaughterhouse

Impact category and unit	Impact per kg of carcass
GHG total (kg CO_2 eqv)	3.2
GHG biogenic (kg CO_2 eqv)	0.7
GHG fossil (kg CO_2 eqv)	2.5
GHG LULUC (kg CO_2 eqv)	0.04
Land occupation (m^2)	6.5
Biodiversity (PDF)	4.3
Eutrophication, marine (kg N eqv)	0.01
Eutrophication, freshwater (kg P eqv)	8.6E-04
Eutrophication, terrestrial (mol N eqv)	0.23
Particulate matter (disease inc.)	4.3E-07
Acidification (mol H+ eqv)	0.06
Water use[5] (m3 depriv.)	0.51

---

[5] Deprivation-weighted water use

3.4.1 Climate change

The GHG emissions from pig is shown in Figure 25. Most of the emissions occur in feed production and on the farm. CO_2 from use of fuel for tillage and harvesting in feed production is the largest single emission and accounts for 37% of total GHG emissions. Methane from manure storage is about 15% of total GHG emissions. Emissions of nitrous oxide (N_2O) occur both from the storage of manure (3%) and spreading of fertiliser in feed production (13%).

Only a small part of GHG emissions from imported feed is from LUC, as mentioned in section 2.6, this is based on data for soybean meal from Denofa's production. CO_2 emissions from the slaughterhouse are from energy use is 7% of total GHG emissions. Other CO_2 emission comes from transport (5% of total GHG) and energy use at the farm (6% of total GHG).

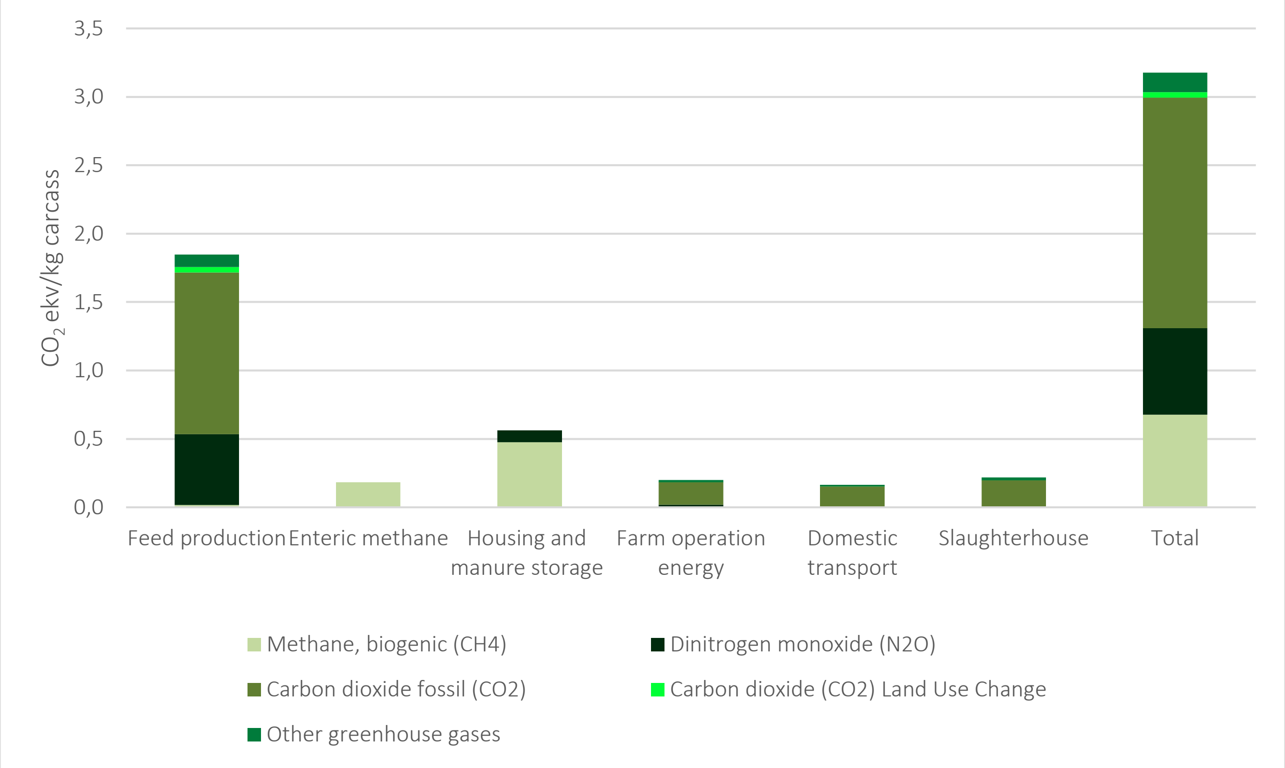

Figure 25 Climate change (CO_2 eqv.) per kg carcass of pig through the life cycle (cradle to slaughterhouse gate)

3.4.2 Land occupation

Land occupation for production of feed and energy production, industry and roads are shown in Figure 26. The land occupation is distributed for the feed categories carbohydrates (barley, oats, wheat, wheat bran, maize, molasses), protein (soybean meal, rapeseed meal, fish meal, faba beans and peas), fat (animal fat) and minerals and vitamins. Land occupation for production of carbohydrates represents 85% of the total area, protein 11 % and fat 1%.

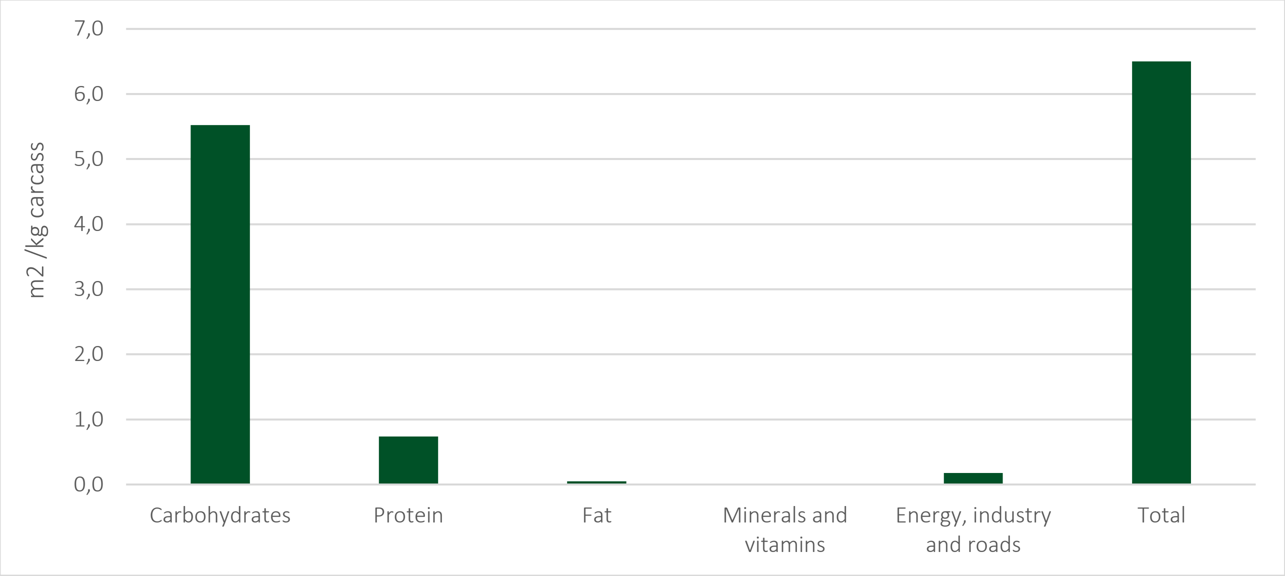

Figure 26 Land occupation (m^2) distributed by land category per kg carcass of pig through the life cycle (cradle to the slaughterhouse gate).

3.4.3 Eutrophication

Eutrophication for freshwater (P eqv.), marine (N eqv.) and terrestrial (moles N eqv.) systems occurs due to emissions of nitrogen and phosphorus compounds, see further description of the method in section 2.5.4 Figure 27 shows the impact from each life cycle step as percentage of total impact for each category. The figure shows that most emissions are linked to feed production for marine and freshwater eutrophication. For terrestrial eutrophication 65% of the impacts is due to housing and manure storage, and feed production is 29%. Emissions from the slaughterhouse is between 4-8% of the total eutrophication impacts.

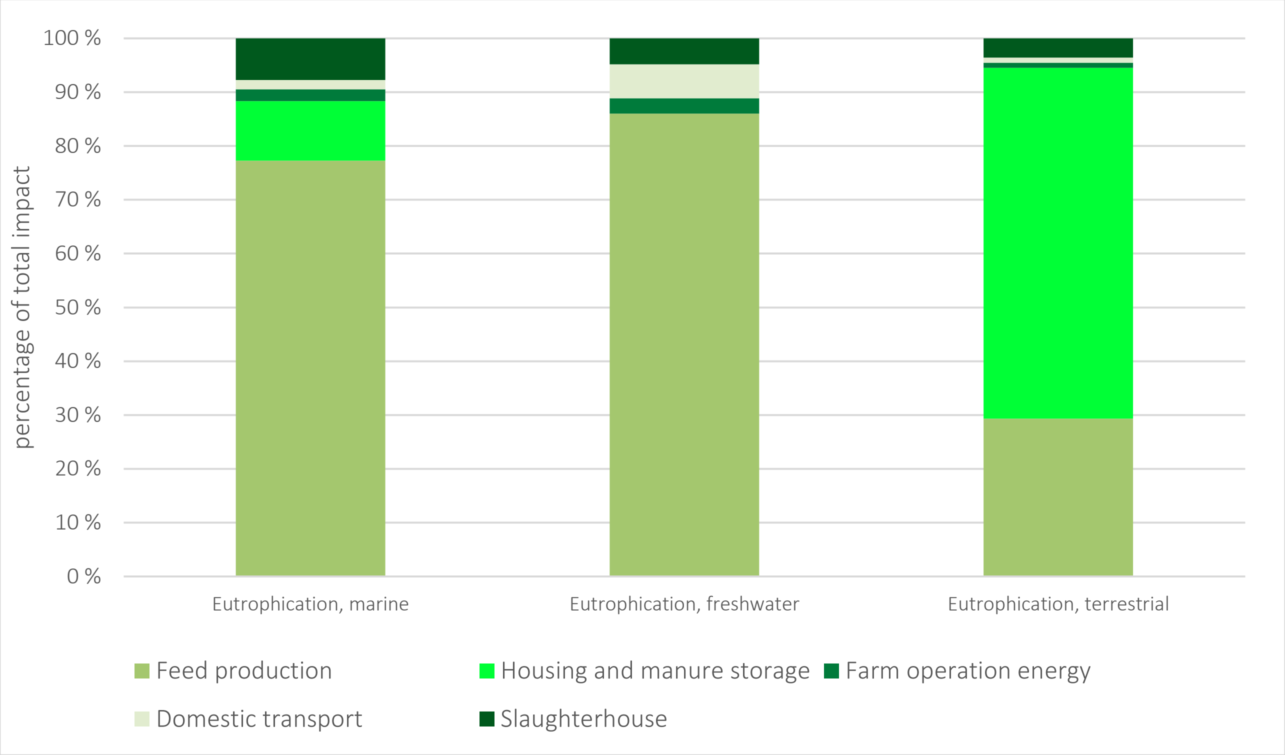

Figure 27 Marine eutrophication, freshwater eutrophication, and terrestrial eutrophication per kg carcass of pig through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category.

3.4.4 Particulate matter

Particulate matter is an expression of the impact of the emissions of respiratory inorganics on human health and is measured in "Disease Incidence", see section 2.5.5 Figure 28 shows the impacts throughout the life cycle and the largest emissions occur in feed production (37%) and housing and manure storage (53%). The impacts to particulate matter are mainly from emissions of ammonia and nitrogen dioxide.

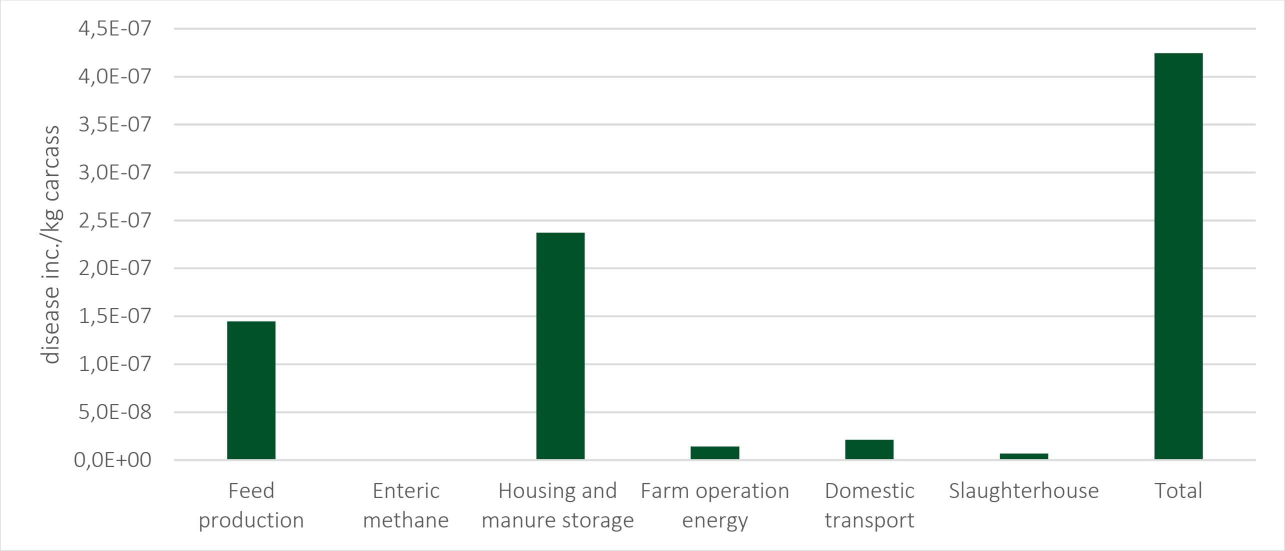

Figure 28 Particulate matter (disease inc.) per kg carcass of pig through the life cycle (cradle to slaughterhouse gate).

3.4.5 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 29, and therefore the impact from acidification is quite similar to that from particulate matter (section 3.1.5 as it is the same type of emissions, but which potentially cause different environmental impacts. The largest emissions occur in domestic feed production (36%) and housing and manure storage (57%).

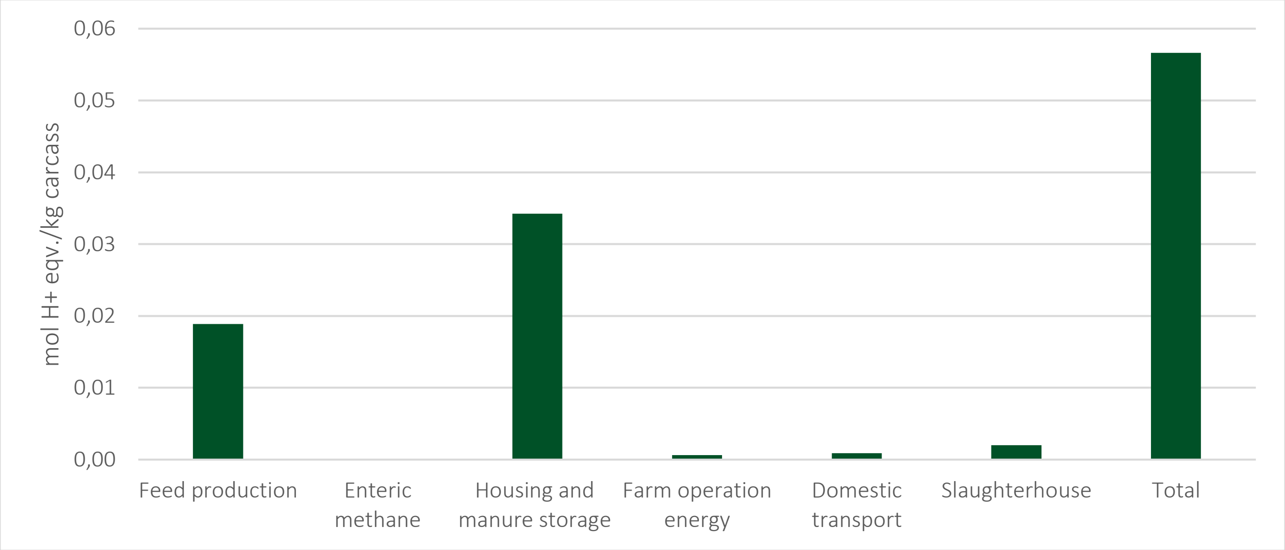

Figure 29 Acidification (mol H^+ eqv.) per kg carcass of pig through the life cycle (cradle to slaughterhouse gate).

3.4.6 Water use

Water is an extremely scarce resource in some regions of the world, while water supplies are plentiful in other regions. The AWARE method used here therefore adjusts absolute water use with regionalized factors and it quantifies Available WAter REmaining per unit area. The characterization factors vary between 0.1 and 100 and are measured in m^3 world equivalent.

Figure 30 shows that feed production has the largest water use (77%), followed by slaughterhouse (10%), and housing (6%). In feed production, the water is mainly used for pesticide dilution, production of fertiliser, and irrigation. The water consumption at the slaughterhouse, the largest part of water consumption is linked to the production of energy and materials. Water use in housing is drinking water for the livestock.

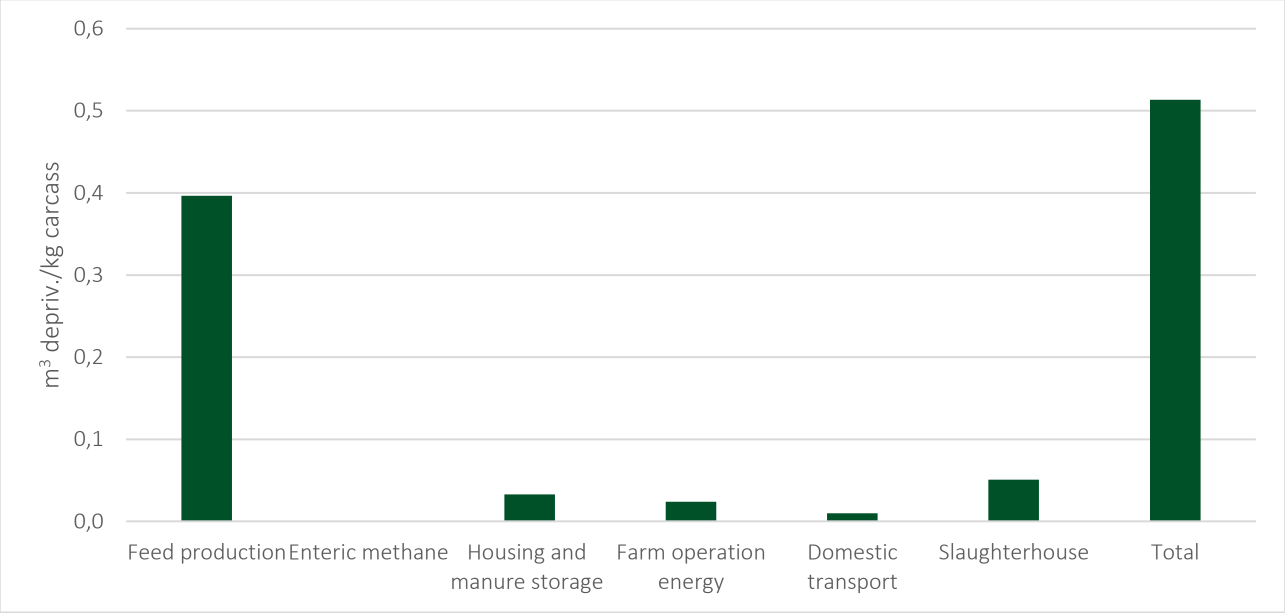

Figure 30 Water use (m^3 depriv.) per kg carcass of pig through the life cycle (cradle to slaughterhouse gate).

3.5 Chicken

The total environmental impacts per kg carcass of chicken are provided in Table 6. Detailed results for each environmental impact throughout the life cycle are shown in the following figures.

However, this does not apply to biodiversity as the method used in this study does not distinguish between different crops and uses the same characterisation factors for arable land. Still, the total value for biodiversity is shown in Table 6 to be able to compare between animal species.

Table 6 Total environmental impacts per kg carcass of chicken at the gate of the slaughterhouse

Impact category and unit	Impact per kg of carcass
GHG total (kg CO_2 eqv)	2.3
GHG biogenic (kg CO_2 eqv)	0.1
GHG fossil (kg CO_2 eqv)	2.1
GHG LULUC (kg CO_2 eqv)	0.04
Land occupation (m^2)	4.4
Biodiversity (PDF)	2.9
Eutrophication, marine (kg N eqv)	0.01
Eutrophication, freshwater (kg P eqv)	6.2E-04
Eutrophication, terrestrial (mol N eqv)	0.12
Particulate matter (disease inc.)	2.0E-07
Acidification (mol H+ eqv)	0.03
Water use[6] (m3 depriv.)	2.1

---

[6] Deprivation-weighted water use

3.5.1 Climate change

The GHG emissions from chicken is shown in Figure 31. Most of the emissions occur in feed production and from energy use at the farm. CO_2 from use of fuel for tillage and harvesting in feed production is the largest single emission and accounts for 44% of total GHG emissions. Emissions of nitrous oxide (N_2O) occur from spreading of fertiliser in feed production (18%) and from the storage of manure (1%).

Only 2% of GHG emissions is from LUC from imported feed. Slaughterhouse CO_2 emissions stems from energy use and is 5% of total GHG emissions. Other CO_2 emission comes from transport (5% of total GHG) and energy use at the farm (18% of total GHG).

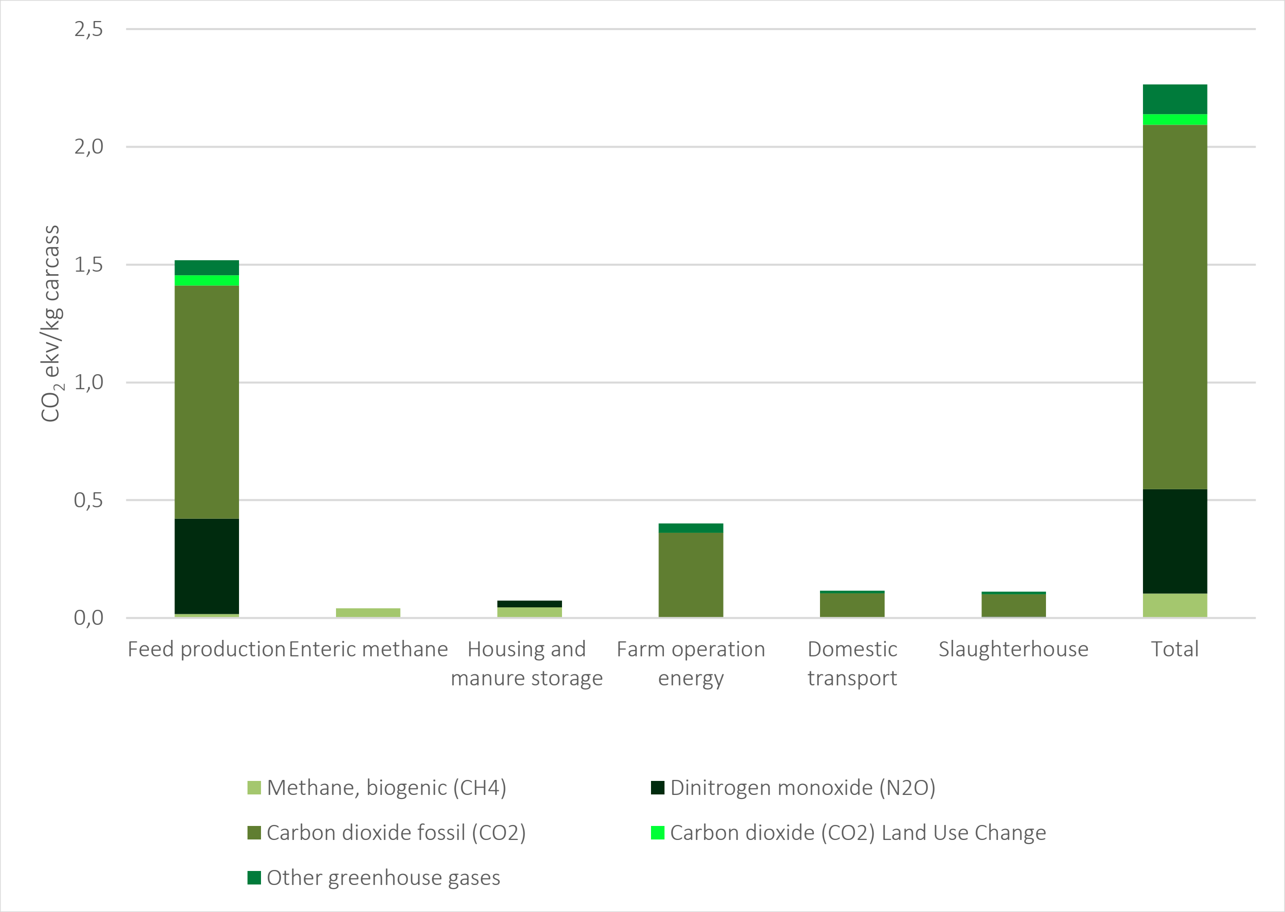

Figure 31 Climate change (CO_2 eqv.) per kg carcass of chicken through the life cycle (cradle to slaughterhouse gate).

3.5.2 Land occupation

Land occupation for production of feed and energy production, industry and roads are shown in Figure 32. The land occupation is distributed for the feed categories carbohydrates (barley, oats, wheat, wheat bran, maize, molasses), protein (soybean meal, rapeseed meal, fish meal, faba beans and peas), fat (animal fat) and minerals and vitamins. Land occupation for production of carbohydrates represents 65% of the total area, protein 30 % and fat 1,5%.

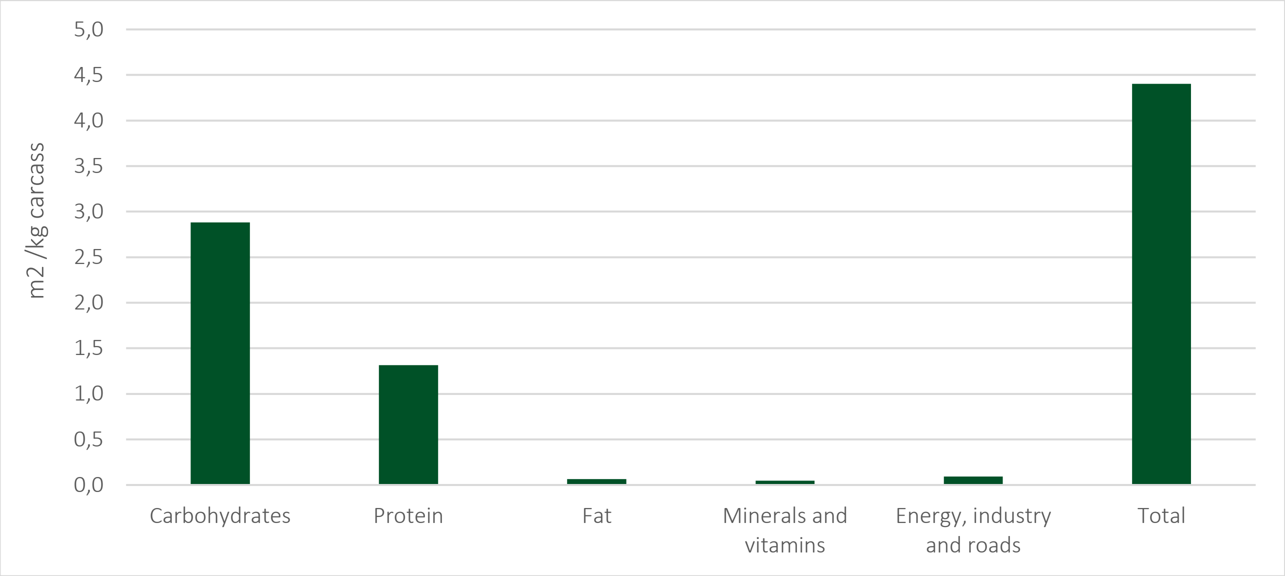

Figure 32 Land occupation (m^2) distributed by land category per kg carcass of chicken through the life cycle (cradle to the slaughterhouse gate).

3.5.3 Eutrophication

Eutrophication for freshwater (P eqv.), marine (N eqv.) and terrestrial (moles N eqv.) systems occurs due to emissions of nitrogen and phosphorus compounds, see further description of the method in section 2.5.4 Figure 33 shows the impact from each life cycle step as percentage of total impact for each category. The figure shows that most emissions are linked to feed production for marine and freshwater eutrophication. For terrestrial eutrophication 43% of the impact is due to housing and manure storage, and feed production is 50%. Emissions from the slaughterhouse is between 5-7% of the total eutrophication impacts.

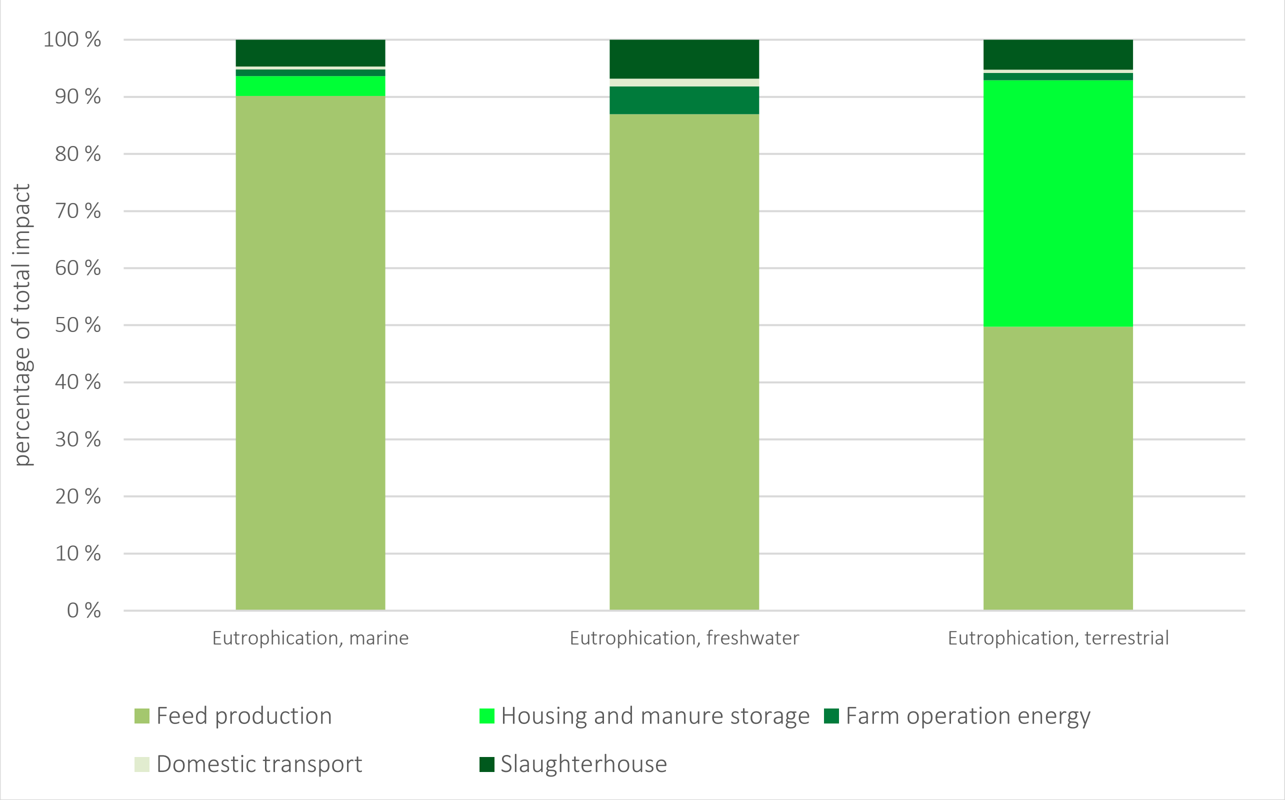

Figure 33 Marine eutrophication, freshwater eutrophication, and terrestrial eutrophication per kg carcass of chicken through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category

3.5.4 Particulate matter

Particulate matter is an expression of the impact of the emissions of respiratory inorganics on human health and is measured in "Disease Incidence", see section 2.5.5 Figure 34 shows the impacts throughout the life cycle and the largest emissions occur in feed production (52%) and housing and manure storage (39%). The impacts to particulate matter are mainly from emissions of ammonia and nitrogen dioxide.

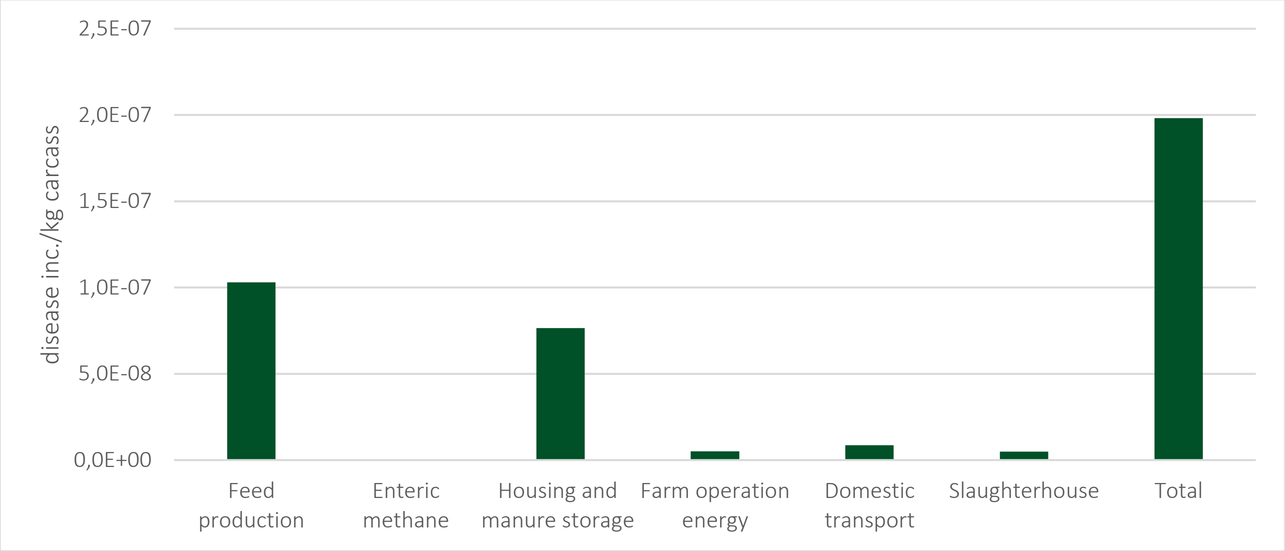

Figure 34 Particulate matter (disease inc.) per kg carcass of chicken through the life cycle (cradle to slaughterhouse gate).

3.5.5 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 35 and therefore the impact from acidification is quite similar to that from particulate matter (section 3.1.5 as it is the same type of emissions, but which potentially cause different environmental impacts. The largest emissions occur in domestic feed production (51%) and housing and manure storage (40%).

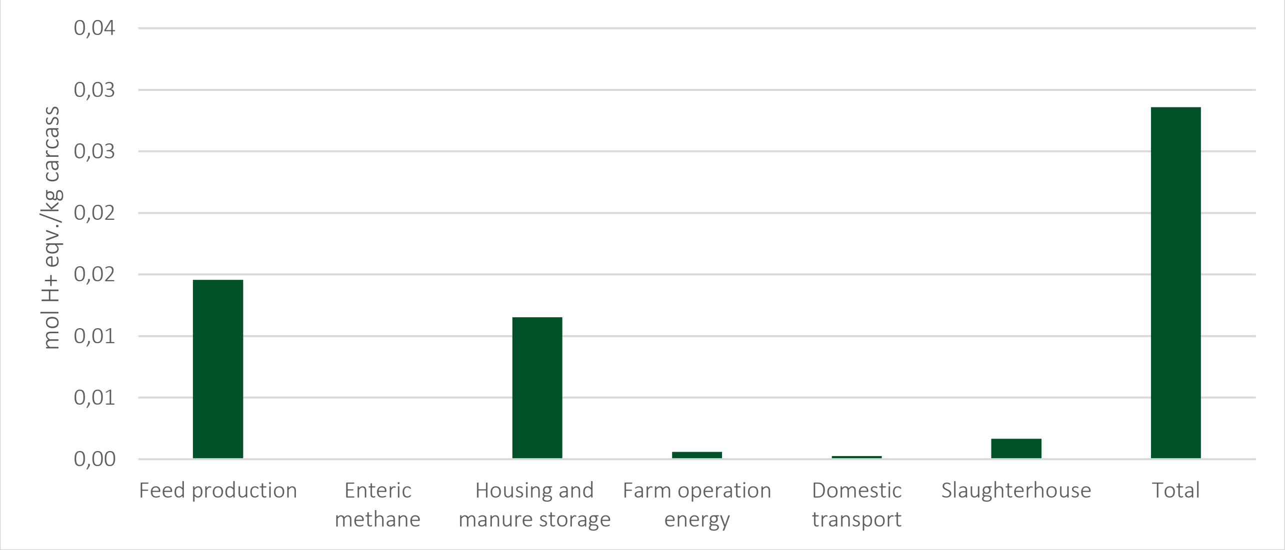

Figure 35 Acidification (mol H^+ eqv.) per kg carcass of chicken through the life cycle (cradle to the gate of the slaughterhouse).

3.5.6 Water use

Water is an extremely scarce resource in some regions of the world, while water supplies are plentiful in other regions. The AWARE method used here therefore adjusts absolute water use with regionalized factors and it quantifies Available WAter REmaining per unit area. The characterization factors vary between 0.1 and 100 and are measured in m^3 world equivalent.

Figure 36 shows that feed production has the largest water use (82%), followed by housing (16%) and slaughterhouse (2%). In feed production, the water is mainly used for pesticide dilution, production of fertiliser, and irrigation. Water use in housing is drinking water for the broiler and the parent generation.

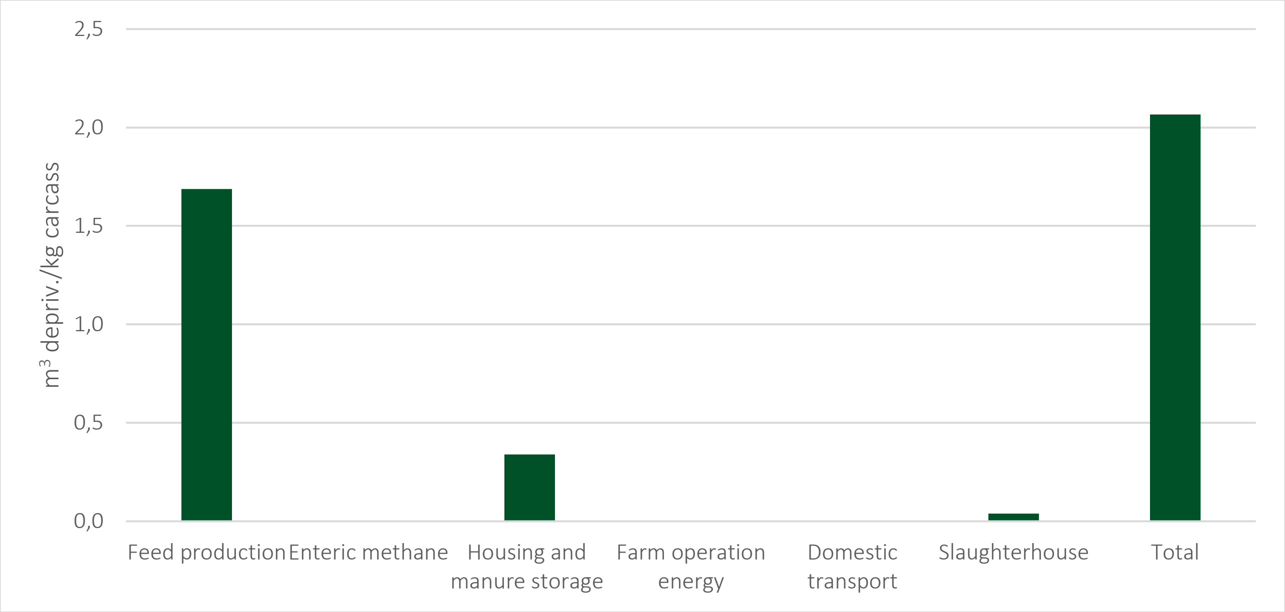

Figure 36 Water use (m^3 depriv.) per kg carcass of chicken through the life cycle (cradle to slaughterhouse gate).

3.6 Turkey

The total environmental impacts per kg carcass of turkey are provided in Table 7. Detailed results for each environmental impact throughout the life cycle are shown in the following figures.

However, this does not apply to biodiversity as the method used in this study does not distinguish between different crops and uses the same characterisation factors for arable land. Still, the total value for biodiversity is shown in Table 7 to be able to compare between animal species.

Table 7 Total environmental impacts per kg carcass of turkey at the gate of the slaughterhouse

Impact category and unit	Impact per kg of carcass
GHG total (kg CO_2 eqv)	2.4
GHG biogenic (kg CO_2 eqv)	0.2
GHG fossil (kg CO_2 eqv)	2.1
GHG LULUC (kg CO_2 eqv)	0.07
Land occupation (m^2)	6.4
Biodiversity (PDF)	4.1
Eutrophication, marine (kg N eqv)	0.01
Eutrophication, freshwater (kg P eqv)	5.9E-04
Eutrophication, terrestrial (mol N eqv)	0.36
Particulate matter (disease inc.)	6.0E-07
Acidification (mol H+ eqv)	0.08
Water use[7] (m3 depriv.)	1.8

---

[7] Deprivation-weighted water use

3.6.1 Climate change

The GHG emissions from turkey is shown in Figure 37. Most of the emissions occur in feed production and on the farm. CO_2 from use of fuel for tillage and harvesting in feed production is the largest single emission and accounts for 44% of total GHG emissions. Emissions of nitrous oxide (N_2O) in feed production is from spreading of fertiliser (23%).

Emissions from manure storage is methane, 3% of total GHG and nitrous oxide (N_2O) 6% of total GHG.

Only 3% of GHG emissions is from LUC from imported feed. CO_2 emissions from the slaughterhouse are from energy use is 2% of total GHG emissions. Other CO_2 emission comes from transport (7% of total GHG) and energy use at the farm (4% of total GHG).

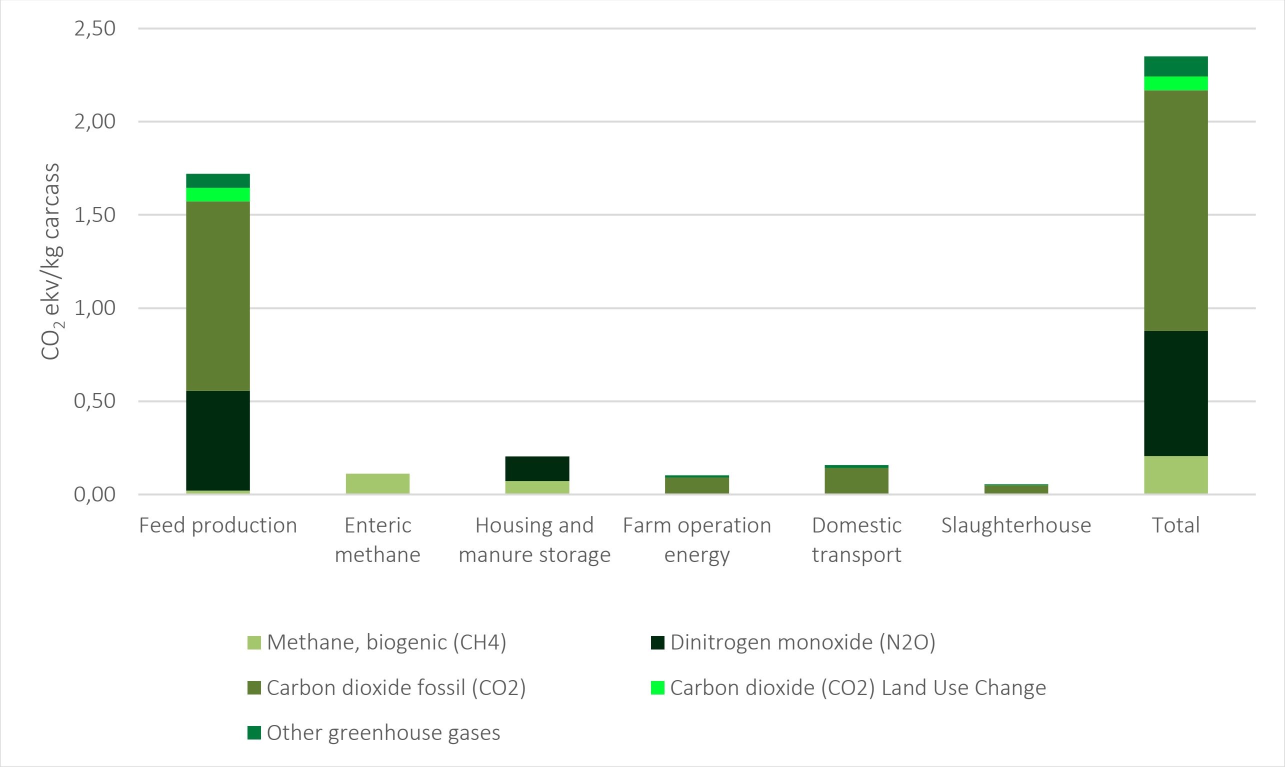

Figure 37 Climate change (CO_2 eqv.) per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate).

3.6.2 Land occupation

Land occupation for production of feed and energy production, industry and roads are shown in Figure 38. The land occupation is distributed for the feed categories carbohydrates (barley, oats, wheat, wheat bran, maize, molasses), protein (soybean meal, rapeseed meal, fish meal, faba beans and peas), fat (animal fat) and minerals and vitamins. Land occupation for production of carbohydrates represents 75% of the total area, protein 18 % and fat 1,4%.

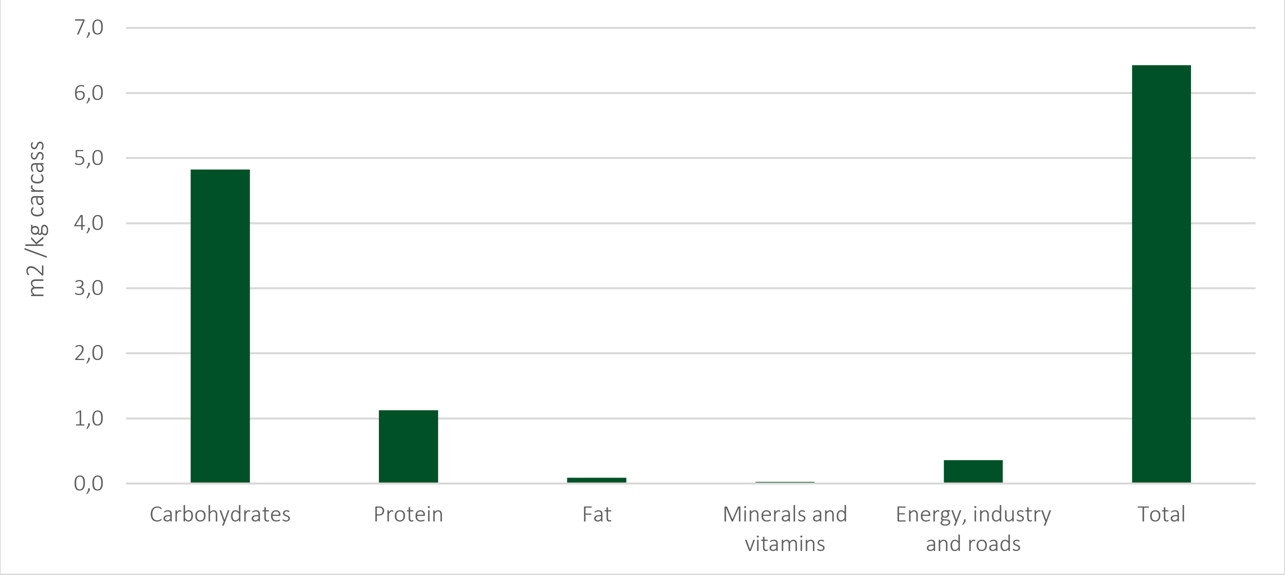

Figure 38 Land occupation (m^2) distributed by land category per kg carcass of turkey through the life cycle (cradle to the slaughterhouse gate).

3.6.3 Eutrophication

Eutrophication for freshwater (P eqv.), marine (N eqv.) and terrestrial (moles N eqv.) systems occurs due to emissions of nitrogen and phosphorus compounds, see further description of the method in section 2.5.4 Figure 39 shows the impact from each life cycle step as percentage of total impact for each category. The figure shows that most emissions are linked to feed production for marine and freshwater eutrophication. For terrestrial eutrophication 77% of the emissions is due to emissions from housing and manure storage, and feed production is 22%. Emissions from the slaughterhouse is about 1% of the total eutrophication impacts.

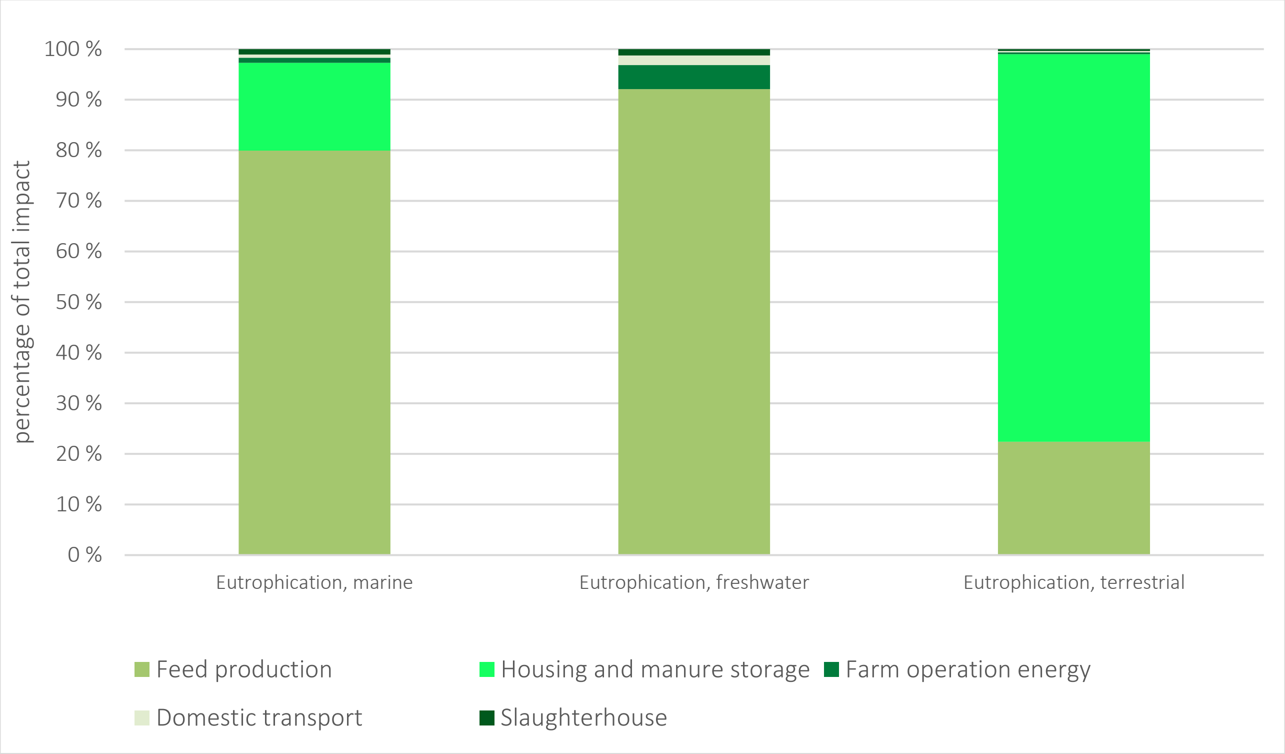

Figure 39 Marine eutrophication, freshwater eutrophication, and terrestrial eutrophication per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category.

3.6.4 Particulate matter

Particulate matter is an expression of the impact of the emissions of respiratory inorganics on human health and is measured in "Disease Incidence", see section 2.5.5 Figure 40 shows the impacts throughout the life cycle and it can be seen that the largest emissions occur in feed production (23%) and housing and manure storage (72%). The impacts to particulate matter are mainly from emissions of ammonia and nitrogen dioxide.

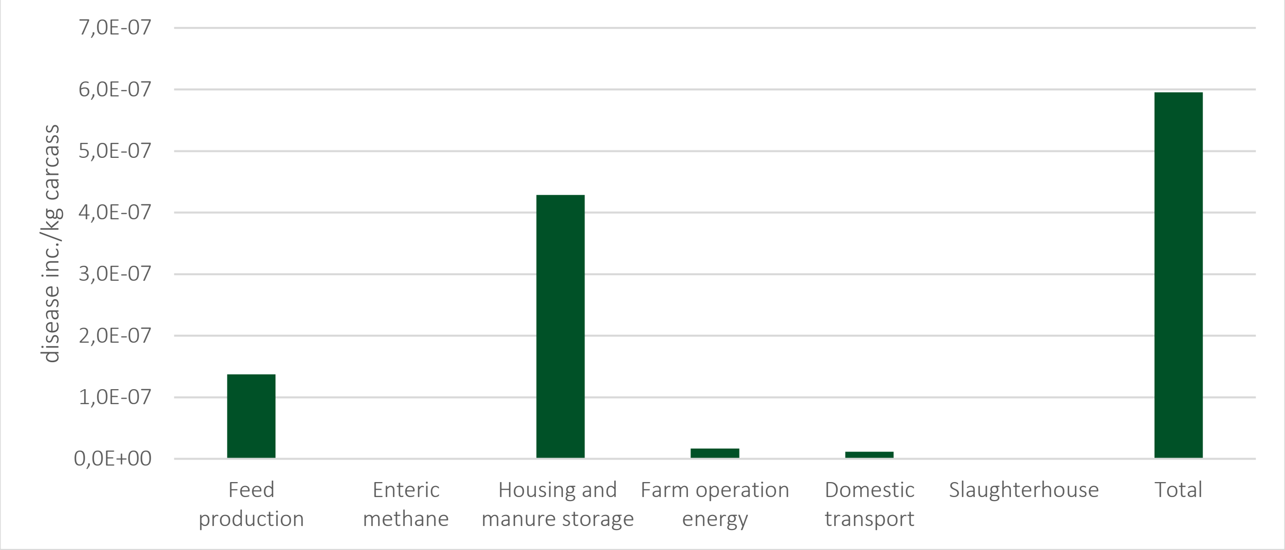

Figure 40 Particulate matter (disease inc.) per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate).

3.6.5 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 41, and therefore the impact from acidification is quite similar to that from particulate matter (section 3.1.5 as it is the same type of emissions, but which potentially cause different environmental impacts. The largest emissions occur in domestic feed production (23%) and housing and manure storage (75%).

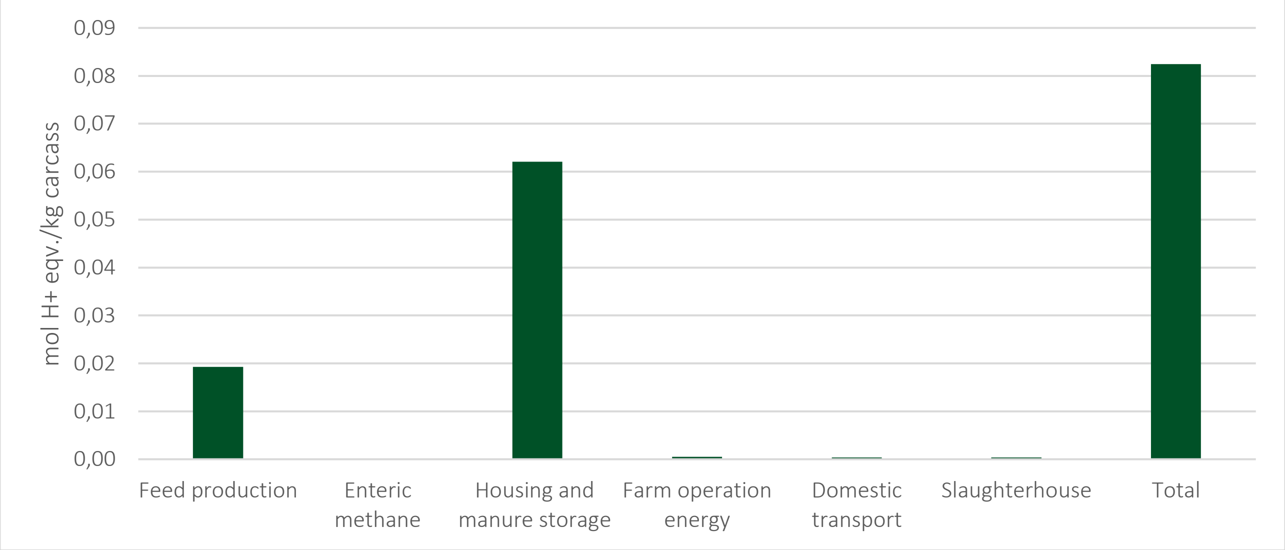

Figure 41 Acidification (mol H^+ eqv.) per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate).

3.6.6 Water use

Water is an extremely scarce resource in some regions of the world, while water supplies are plentiful in other regions. The AWARE method used here therefore adjusts absolute water use with regionalized factors and it quantifies Available WAter REmaining per unit area. The characterization factors vary between 0.1 and 100 and are measured in m^3 world equivalent.

Figure 42 shows that feed production has the largest water use (91%), followed by housing (5%), and slaughterhouse (1%). In feed production, the water is mainly used for pesticide dilution, production of fertiliser, and irrigation. Water use in housing is drinking water for the turkey and the parent generation.

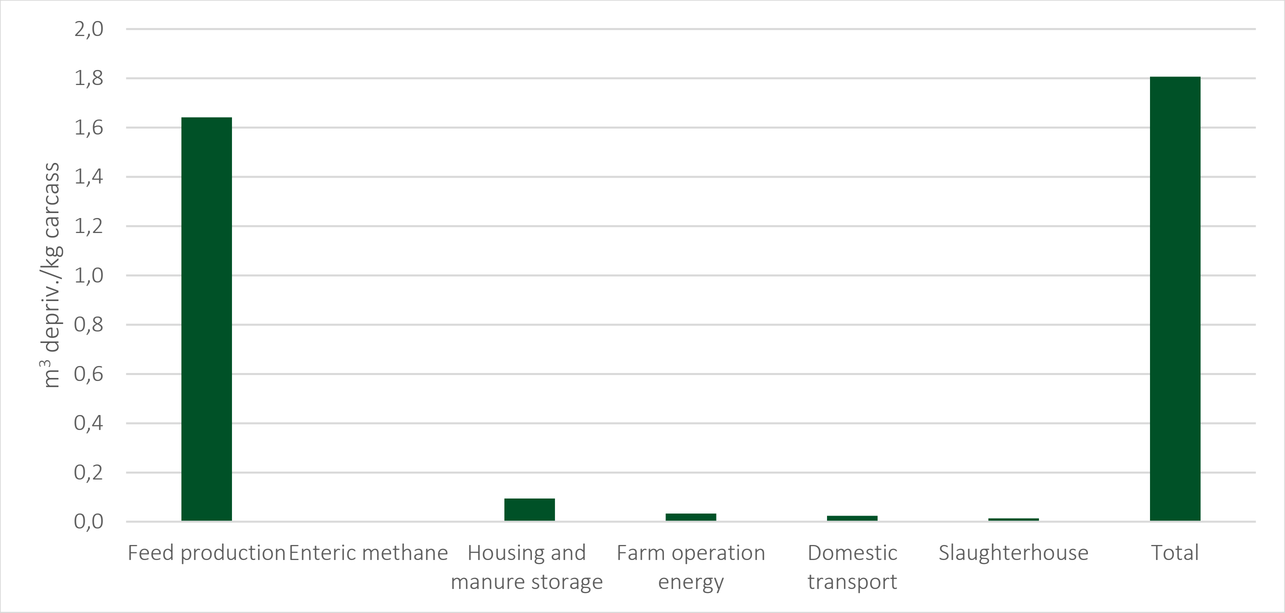

Figure 42 Water use (m^3 depriv.) per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate).

3.7 Egg

The total environmental impacts per kg egg are provided in Table 8. Detailed results for each environmental impact throughout the life cycle are shown in the following figures.

However, this does not apply to biodiversity as the method used in this study does not distinguish between different crops and uses the same characterisation factors for arable land. Still, the total value for biodiversity is shown in Table 8 to be able to compare between animal species.

Table 8 Total environmental impacts per kg egg at the gate of the egg packing and processing plant

Impact category and unit	Impact per kg egg
GHG total (kg CO_2 eqv)	1.5
GHG biogenic (kg CO_2 eqv)	0.1
GHG fossil (kg CO_2 eqv)	1.4
GHG LULUC (kg CO_2 eqv)	0.05
Land occupation (m^2)	3.6
Biodiversity (PDF)	2.4
Eutrophication, marine (kg N eqv)	0.01
Eutrophication, freshwater (kg P eqv)	4.1E-04
Eutrophication, terrestrial (mol N eqv)	0.12
Particulate matter (disease inc.)	2.0E-07
Acidification (mol H+ eqv)	0.03
Water use[8] (m3 depriv.)	1.4

---

[8] Deprivation-weighted water use

3.7.1 Climate change

The GHG emissions from egg is shown in Figure 43. Most of the emissions occur in feed production. CO_2 from use of fuel for tillage and harvesting in feed production is the largest single emission and accounts for 47% of total GHG emissions. Nitrous oxide from spreading of fertiliser in feed production (23%).

Emissions from manure storage is methane, 4% of total GHG and nitrous oxide (N_2O) 2% of total GHG.

Only 3% of GHG emissions is from LUC from imported feed. CO_2 emissions from the egg packing and processing plant are from energy use is 1% of total GHG emissions. Other CO_2 emission comes from transport (9% of total GHG) and energy use at the farm (5% of total GHG).

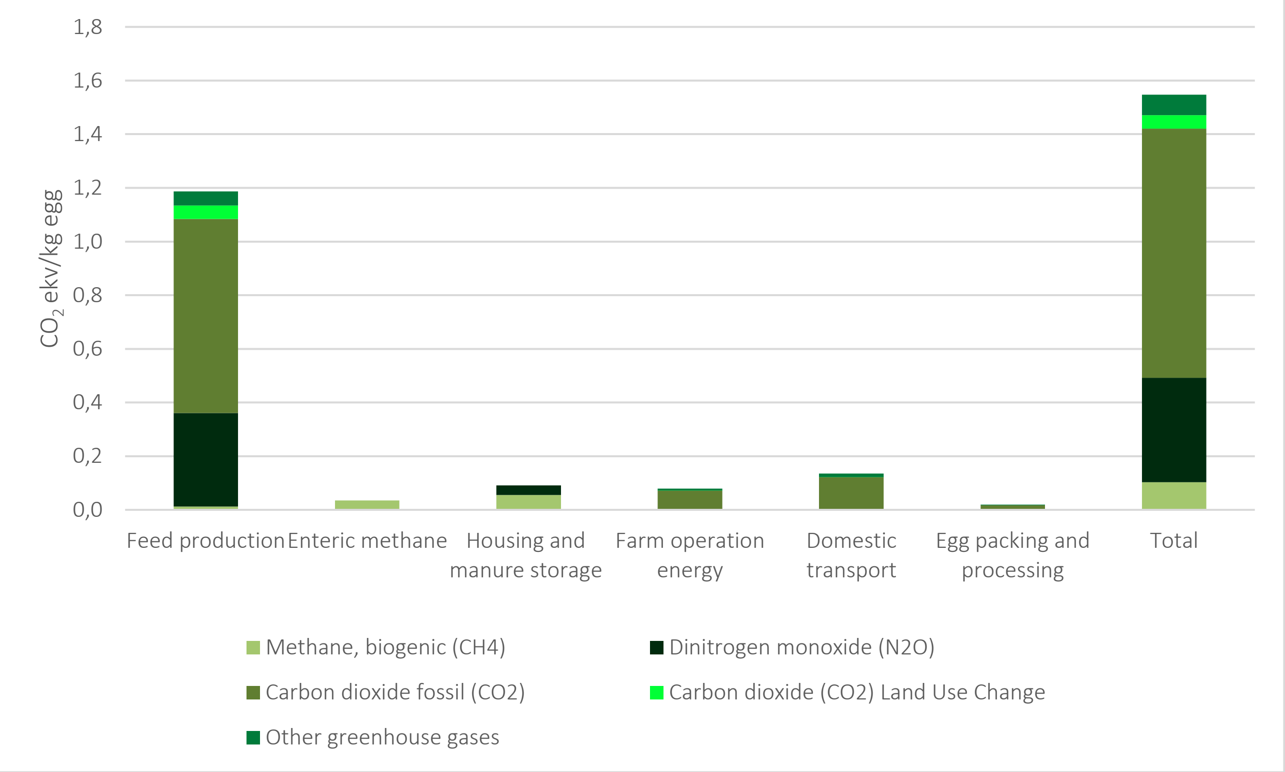

Figure 43 Climate change (CO_2 eqv.) per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant)

3.7.2 Land occupation

Land occupation for production of feed and energy production, industry and roads are shown in Figure 44. The land occupation is distributed for the feed categories carbohydrates (barley, oats, wheat, wheat bran, maize, molasses), protein (soybean meal, rapeseed meal, fish meal, faba beans and peas), fat (animal fat) and minerals and vitamins. Land occupation for production of carbohydrates represents 83% of the total area, protein 14 % and fat 1,2%.

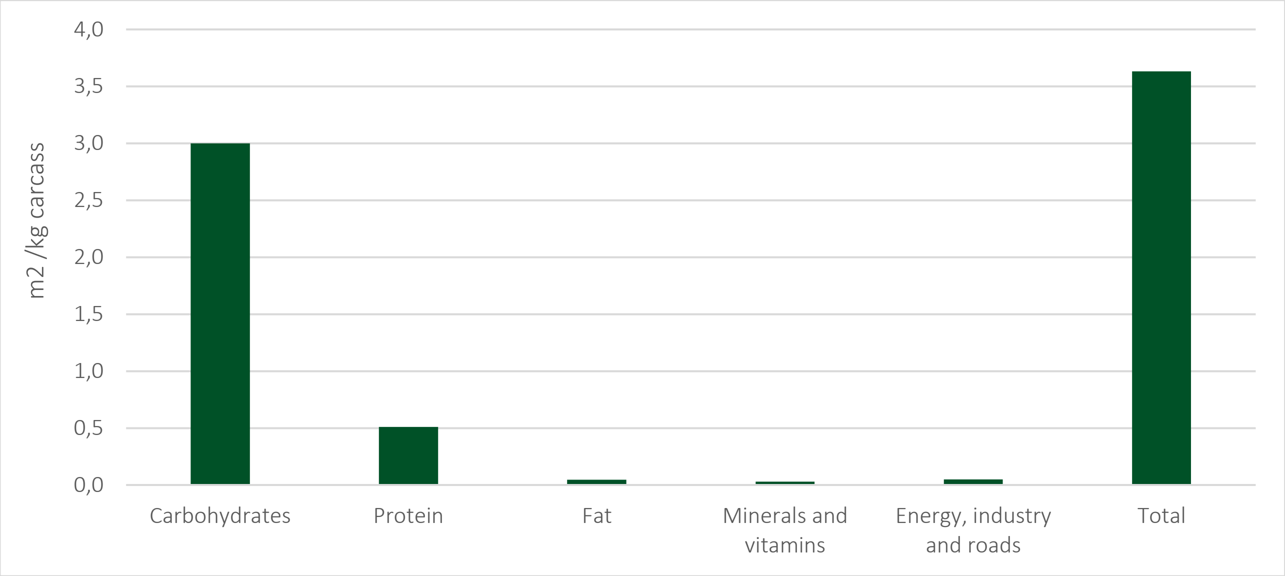

Figure 44 Land occupation (m^2) distributed by land category per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant).

3.7.3 Eutrophication

Eutrophication for freshwater (P eqv.), marine (N eqv.) and terrestrial (moles N eqv.) systems occurs due to emissions of nitrogen and phosphorus compounds, see further description of the method in section 2.5.4 Figure 45 shows the impact from each life cycle step as percentage of total impact for each category. The figure shows that most emissions are linked to feed production for marine and freshwater eutrophication. For terrestrial eutrophication 45% of the emissions is due to emissions from housing and manure storage, and feed production is 53%.

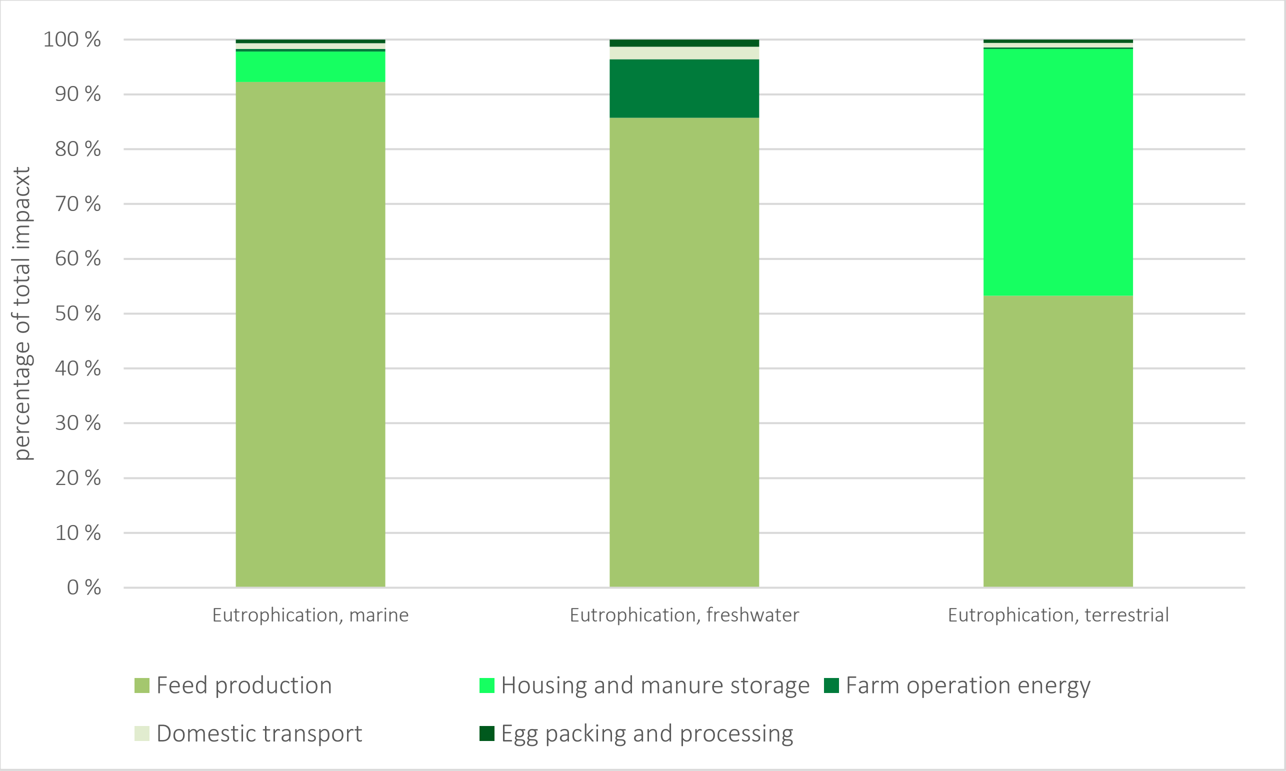

Figure 45 Marine eutrophication, freshwater eutrophication, and terrestrial eutrophication per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant) as percentage of total impact for each category.

3.7.4 Particulate matter

Particulate matter is an expression of the impact of the emissions of respiratory inorganics on human health and is measured in "Disease Incidence", see section 2.5.5 Figure 46 shows the impacts throughout the life cycle and the largest emissions occur in feed production (54%) and housing and manure storage (40%). The impacts to particulate matter are mainly from emissions of ammonia and nitrogen dioxide.

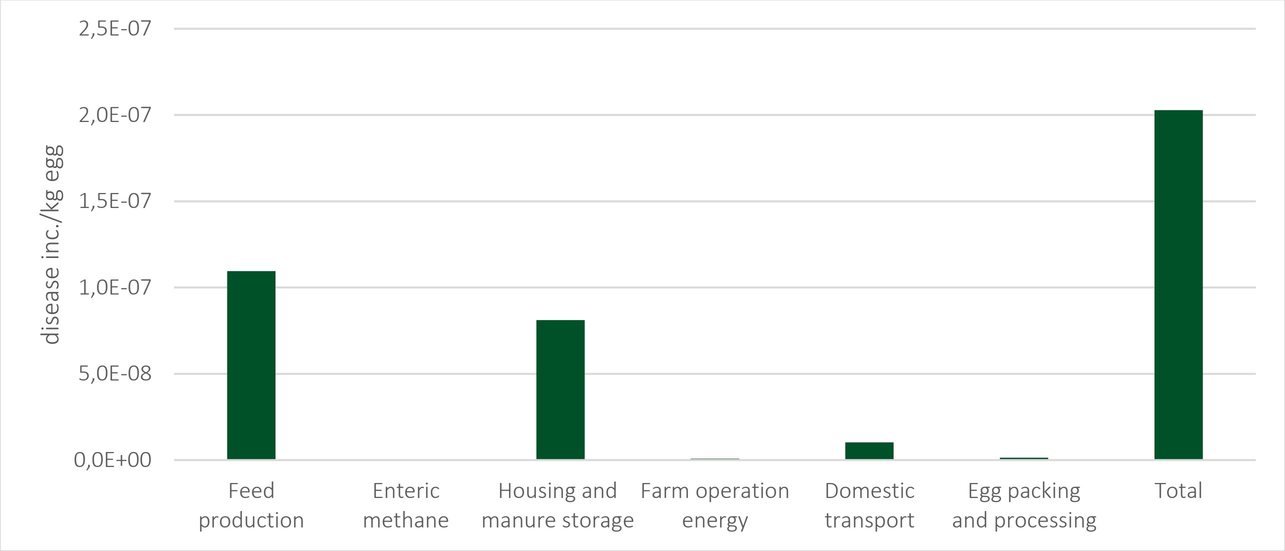

Figure 46 Particulate matter (disease inc.) per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant).

3.7.5 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 47, and therefore the impact from acidification is quite similar to that from particulate matter (section 3.1.5 as it is the same type of emissions, but which potentially cause different environmental impacts. The largest emissions occur in domestic feed production (55%) and housing and manure storage (43%).

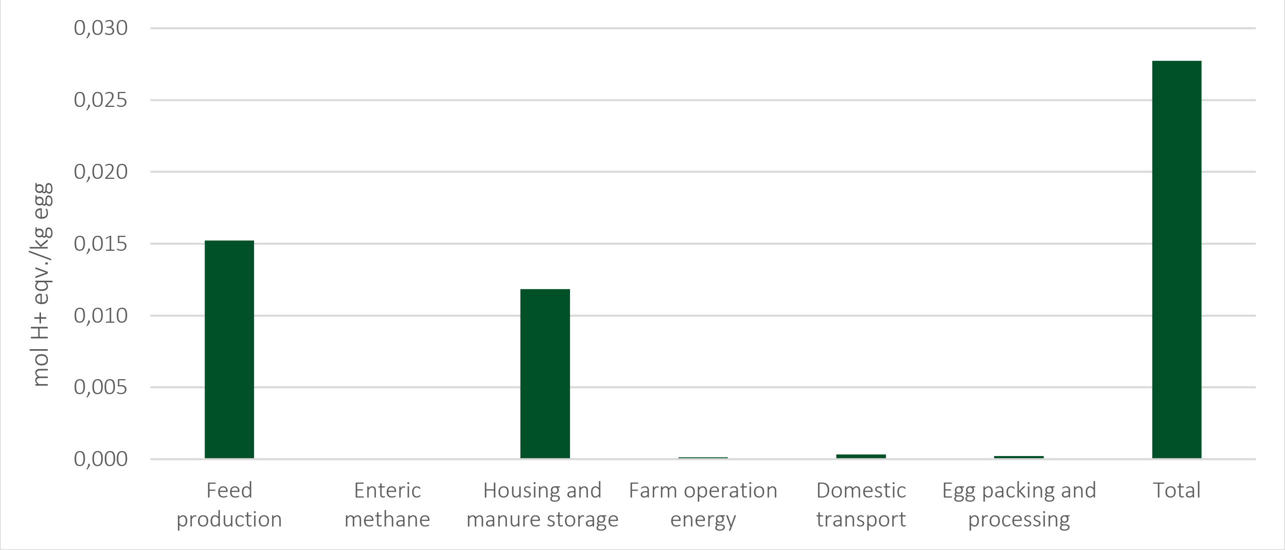

Figure 47 Acidification (mol H^+ eqv.) per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant).

3.7.6 Water use

Water is an extremely scarce resource in some regions of the world, while water supplies are plentiful in other regions. The AWARE method used here therefore adjusts absolute water use with regionalized factors and it quantifies Available WAter REmaining per unit area. The characterization factors vary between 0.1 and 100 and are measured in m^3 world equivalent.

Figure 48 shows that feed production has the largest water use (75%), followed by housing (16%), and egg packing and processing plant (8%). In feed production, the water is mainly used for pesticide dilution, production of fertiliser and irrigation. Water use in housing is drinking water for the laying hen and the parent generation.

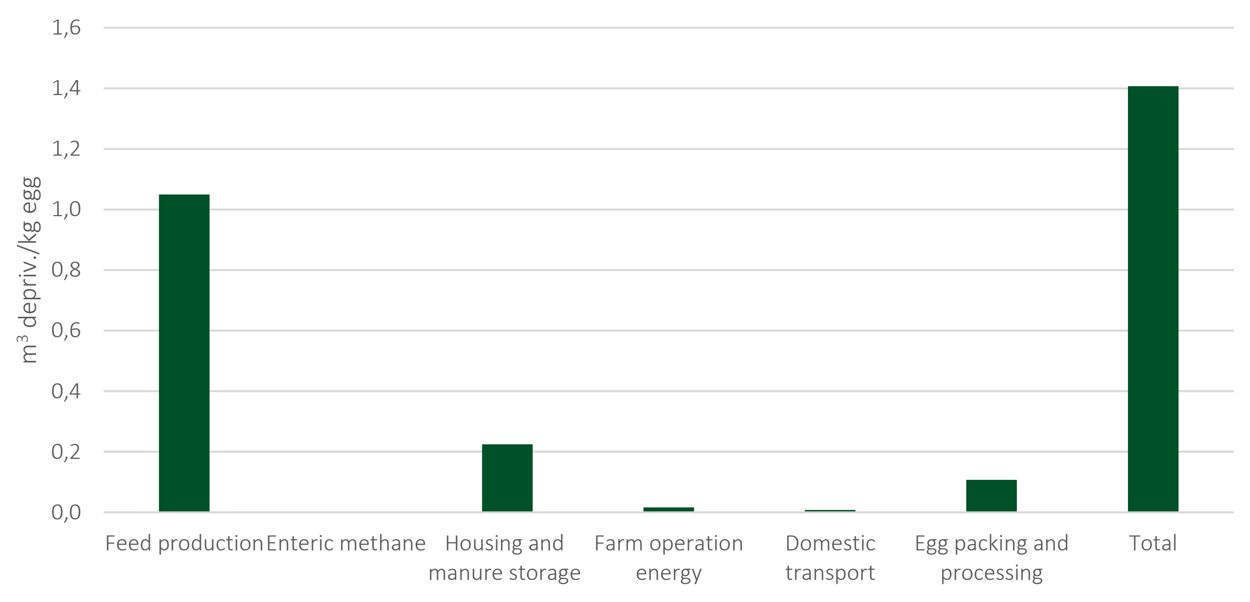

Figure 48 Water use (m^3 depriv.) per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant).

4 Conclusion and further work

The environmental impact of meat and egg produced in Norway published in this report is based on the average production levels in Norway, giving valuable knowledge of the current situation for the domestic production of meat and egg. The results are a documentation of the current production and gives a starting point for discussing and evaluating future measures for improving the sustainability of the value chain. Inclusion of several impact categories such as climate change, land occupation, biodiversity, eutrophication, particulate matter, and acidification will to a greater extent lead to avoid problem shifting as the impact categories are influenced by different parts of the production. However, there are large variability among individual farms, which is not accounted for when assessing the impact from average farms and average production levels. Thus, documentation of the variability among individual farms is a valuable addition to this report when evaluating measures and future changes in the value chain.

Table 9 shows a compilation of the total environmental impacts for all animal species per kg carcass and egg.

Table 9 Total environmental impacts per kg carcass and egg from cradle to industry gate.

Impact category and unit	Beef dairy cattle	Beef beef cattle	Mutton and lamb	Pork	Chicken	Turkey	Egg
GHG total ($kg\ CO_2$ eqv)	21.6	30.0	26.1	3.2	2.3	2.4	1.5
GHG biogenic ($kg\ CO_2$ eqv)	10.2	16.3	11.7	0.7	0.1	0.2	0.1
GHG fossil ($kg\ CO_2$ eqv)	11.0	13.6	14.3	2.5	2.1	2.1	1.4
GHG LULUC ($kg\ CO_2$ eqv)	0.5	0.1	0.1	0.04	0.04	0.07	0.05
Land occupation, excl. outfields (m^2)	27	28	28	6.5	4.4	6.4	3.6
Biodiversity (PDF)	7.0	-14	-41	4.3	2.9	4.1	2.4
Eutrophication, marine (kg N eqv)	0.05	0.04	0.06	0.01	0.01	0.01	0.01
Eutrophication, freshwater (kg P eqv)	0.014	0.011	0.011	8.6E-04	6.2E-04	5.9E-04	4.1E-04
Eutrophication, terrestrial (mol N eqv)	1.9	2.5	1.8	0.23	0.12	0.36	0.12
Particulate matter (disease inc.)	2.7E-06	3.8E-06	2.4E-06	4.3E-07	2.0E-07	6.0E-07	2.0E-07
Acidification (mol H+ eqv)	0.41	0.56	0.39	0.06	0.03	0.08	0.03
Water use (m^3 depriv.)	1.8	0.58	0.76	0.51	2.1	1.8	1.4

For the ruminant's dairy cattle, beef cattle and sheep, a large part of the greenhouse gas emissions (GHG) arises from enteric methane. A large part also comes from N_2O from housing and manure storage. For the monogastric animals' pig, chicken, turkey and laying hen, N_2O from use of fertiliser and CO_2 emissions from feed production make up the largest proportion of greenhouse gases. In addition, a varying proportion comes from methane and N_2O from housing and manure storage.

For particulate matter and acidification, the largest emissions occur in feed production, housing and manure storage and the same applies to the various eutrophication categories.

Feed production for monogastric animals takes place exclusively on arable land. For dairy cattle, the feed production is mainly linked to grassland for grass silage production and pasture but also arable land for grain production. For beef cattle and sheep, a larger part of the feed is sourced from grazing in permanent pasture and outfields. Loss of biodiversity is assessed based on plant species richness. Because beef cattle and sheep production are based on a large proportion of grazing, these productions contribute to increased biodiversity. Correspondingly, the use of areas for grass production in cereal crop rotation will result in loss of biodiversity. Because most of the feed for dairy cattle and monogastric livestock comes from such areas, the net contribution from these productions will result in a loss of biodiversity.

The differences in water use are mainly due to feed production, especially the poultry feed contains imported feed ingredients which have an impact because the characterization factors are regionalized for water in the AWARE (Available WAter Remaining) method, i.e. they take into account the availability of water in each individual country.

The results for meat in this study are calculated for kg carcass. It is also relevant to calculate environmental impacts for boneless meat and work is underway to provide good and reliable conversion factors for each animal species. In addition, allocation factors must also be calculated for by-products from the slaughtering process, so that the total environmental burden can be distributed to all the outflows from the process based on their economic value.

5 References

Allen, M. R., Shine, K. P., Fuglestvedt, J. S., Millar, R. J., Cain, M., Frame, D. J., & Macey, A. H. (2018). A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. *npj Climate and Atmospheric Science, 1*(1), 16. doi:10.1038/s41612-018-0026-8

Andrén, O., & Kätterer, T. (1997). ICBM: The introductiory carbon balance model for exploration of soil carbon balances. *Ecological Applications, 7*(4), 1226-1236. doi:https://doi.org/10.1890/1051-0761(1997)007[1226:ITICBM]2.0.CO;2

Andrén, O., Kätterer, T., & Karlsson, T. (2004). ICBM regional model for estimations of dynamics of agricultural soil carbon pools. *Nutrient Cycling in Agroecosystems, 70*(2), 231-239. doi:10.1023/B:FRES.0000048471.59164.ff

Animalia. (2021a). *Norwegian Beef Cattle Recording System – Digital Annual Report 2021*. Retrieved from Oslo: https://www.animalia.no/no/Dyr/husdyrkontrollene/storfekjottkontrollen/arsmeldinger/

Animalia. (2021b). *Norwegian Sheep Recording System – Digital Annual Report 2021.* Retrieved from Oslo: https://www.animalia.no/no/Dyr/husdyrkontrollene/sauekontrollen/arsmeldinger/

Animalia, Kjos, A.-K., Nafstad, O., Odden, H., Ruud, T. A., Saltnes, T., & Ytterdah, l. (2022). *Kjøttets tilstand 2022 - Status i norsk kjøtt- og eggproduksjon (Status in Norwegian meat and egg production 2022)*. Retrieved from https://www.animalia.no/contentassets/230925d6c1af4b458b9bfed7cff05aef/228470-kt22-hele-korr12-dsc.pdf

Bittman, S., Dedina, M., Howard, C., Oenema, O., & Sutton, M. (2014). *Options for ammonia mitigation: Guidance from the UNECE Task Force on Reactive Nitrogen*: NERC/Centre for Ecology & Hydrology.

Bonesmo, H., Beauchemin, K. A., Harstad, O. M., & Skjelvåg, A. O. (2013). Greenhouse gas emission intensities of grass silage based dairy and beef production: A systems analysis of Norwegian farms. *Livestock Science, 152*(2-3), 239-252. doi:10.1016/j.livsci.2012.12.016

Bonesmo, H., & Enger, E. G. (2021). The effects of progress in genetics and management on intensities of greenhouse gas emissions from Norwegian pork production. *Livestock Science*, 104746. doi:https://doi.org/10.1016/j.livsci.2021.104746

Boulay, A. M., Bare, J., Benini, L., Berger, M., Lathuillière, M. J., Manzardo, A., . . . Pfister, S. (2016). *The WULCA consensus characterization model for water scarcity footprints: Assessing impacts of water consumption based on available water remaining (AWARE)*. Retrieved from

BSI. (2011). PAS 2050:2011. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. In: British Standards Institution.

Carbon Limits. (2018). *Calculation of atmospheric nitrogen emissions from manure in Norwegian agriculture, M-1255|2018. Technical description of the revised model*. Retrieved from https://www.carbonlimits.no/wp-content/uploads/2018/12/Model-report_211218_CL.pdf

Carbon Limits. (2020a). *Calculation of atmospheric nitrogen emissions from manure in Norwegian agriculture, M-1848|2020. Technical description of the revised model*. Retrieved from https://www.miljodirektoratet.no/globalassets/publikasjoner/m1848/m1848.pdf

Carbon Limits. (2020b). *Greenhouse gas emissions from biogas production from manure in Norwegian agriculture, M-1849|2020. Technical description of the revised model*. Retrieved from https://www.miljodirektoratet.no/globalassets/publikasjoner/m1849/m1849.pdf

Cherubini, E. (2020). *Comparative carbon footprint of soybeans, maize and cotton fibre* (Final report: version 1.4). Retrieved from Available on request

EMEP/EEA. (2019). *EMEP/EEA air pollutant emission inventory guidebook 2019*. Retrieved from Luxembourg: https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

European Dairy Association. (2018). *Product Environmental Footprint Category Rules (PEFCR) for Dairy Products*. Retrieved from Belgium: https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR-DairyProducts_2018-04-25_V1.pdf

Fantke, P., Evans, J. R., Hodas, N., Apte, J. S., Jantunen, M. J., Jolliet, O., & McKone, T. E. (2016). Health impacts of fine particulate matter. In *Global guidance for life cycle impact assessment indicators* (pp. 76-99): SETAC.

FEFAC. (2018). *PEFCR Feed for Food Producing Animals. First public version (v4.1)*. Retrieved from https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_feed.pdf

Ingris. (2021). *Ingris Årsstatistikk 2020 (Annual pig production statistic 2020)*. Retrieved from Norway: https://www.animalia.no/contentassets/aad3a2af83fb4029babe7a5707009b75/arsstatistikk-2020-007---endelig.pdf

International Dairy Federation. (2022). *C-Sequ LCA guidelines for calculating carbon sequestration in cattle production systems*. Retrieved from Brussels:

IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*. Retrieved from Japan: https://www.ipcc-nggip.iges.or.jp/public/2006gl/

IPCC. (2013). *Climate Change 2013: The Physical Science Basis, IPCC Working Group, Contribution to AR5 (the Fifth Assessment Report). Available at http://www.climatechange2013.org/*. Retrieved from http://www.climatechange2013.org

IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from Cambridge University Press. In Press:

Karlengen, I. J., Svihus, B., Kjos, N. P., & Harstad, O. M. (2012). *Husdyrgjødsel; oppdatering av mengder gjødsel og utskillelse av nitrogen, fosfor og kalium. Sluttrapport (Livestock manure; updating amounts of fertilizers and excreting nitrogen, phosphorus and potassium. Final report)*. Retrieved from Ås, Norway: http://www.kore.no/wp-content/uploads/2015/02/husdyrgjodsel-oppdatering-av-mengder-gjodsel-og-utskillelse-av-nitrogen-fosfor-og-kalium-sluttrapport-umb.pdf

Knudsen, M. T., Dorca-Preda, T., Djomo, S. N., Peña, N., Padel, S., Smith, L. G., . . . Hermansen, J. E. (2019). The importance of including soil carbon changes, ecotoxicity and biodiversity impacts in environmental life cycle assessments of organic and conventional milk in Western Europe. *Journal of Cleaner Production, 215*, 433-443. doi:10.1016/j.jclepro.2018.12.273

Knudsen, M. T., Hermansen, J. E., Cederberg, C., Herzog, F., Vale, J., Jeanneret, P., . . . Dennis, P. (2017). Characterization factors for land use impacts on biodiversity in life cycle assessment based on direct measures of plant species richness in European farmland in the 'Temperate Broadleaf and Mixed Forest' biome. *Science of The Total Environment, 580*, 358-366. doi:10.1016/j.scitotenv.2016.11.172

Kolle, S. O., & Oguz-Alper, M. (2020). *Bruk av gjødselressurser i jordbruket 2018. Metodebeskrivelse og resultater fra en utvalgsbasert undersøkelse (Use of fertilizer resources in agriculture 2018. Method description and results from a sample-based survey)*. Retrieved from Oslo: https://www.ssb.no/jord-skog-jakt-og-fiskeri/artikler-og-publikasjoner/_attachment/414178?_ts=170a0861638

Meinshausen, M., & Nicholls, Z. (2022). GWP*is a model, not a metric. *Environmental Research Letters, 17*(4), 041002. doi:10.1088/1748-9326/ac5930

Møller, H., Samsonstuen, S., Øverland, M., Modahl, I. S., & Olsen, H. F. (2022). Local non-food yeast protein in pig production - environmental impacts and land use efficiency. *Livestock Science*, 104925. doi:https://doi.org/10.1016/j.livsci.2022.104925

Nortura. (n.d.). Nortura sauefôring. Retrieved from https://medlem.nortura.no/beregningskalkulatorer/nortura-saueforing-article35775-11855.html

Norwegian Environment Agency. (2022). *Greenhouse Gas Emissions 1990 -2020: National Inventory Report* (M-2268). Retrieved from https://www.miljodirektoratet.no/publikasjoner/2022/april/greenhouse-gas-emissions-1990--2020-national-inventory-report/

Novaes, R. M. L., Pazianotto, R. A. A., Brandão, M., Alves, B. J. R., May, A., & Folegatti-Matsuura, M. I. S. (2017). Estimating 20-year land-use change and derived CO2 emissions associated with crops, pasture and forestry in Brazil and each of its 27 states. *Global Change Biology, 23*(9), 3716-3728. doi:https://doi.org/10.1111/gcb.13708

Posch, M., Seppälä, J., Hettelingh, J.-P., Johansson, M., Margni, M., & Jolliet, O. (2008). The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterisation factors for acidifying and eutrophying emissions in LCIA. *The International Journal of Life Cycle Assessment, 13*(6), 477. doi:10.1007/s11367-008-0025-9

Rekdal, Y., & Angeloff, M. (2021). *Arealrekneskap i utmark. Utmarksbeite – ressursgrunnlag og beitebruk* (7(208)). Retrieved from https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2837610

Rogelj, J., & Schleussner, C.-F. (2019). Unintentional unfairness when applying new greenhouse gas emissions metrics at country level. *Environmental Research Letters, 14*(11), 114039. doi:10.1088/1748-9326/ab4928

Samsonstuen, S., Møller, H., Aamaas, B., Knudsen, M. T., Mogensen, L., & Olsen, H. F. (2023). Choice of Metrics Matters – Future Scenarios on Milk and Beef Production in Norway Using an Lca Approach. *Preprint. Available at SSRN*. Retrieved from http://dx.doi.org/10.2139/ssrn.4518481

Samsonstuen, S., Åby, B. A., Crosson, P., Beauchemin, K. A., Bonesmo, H., & Aass, L. (2019). Farm scale modelling of greenhouse gas emissions from semi-intensive suckler cow beef production. *Agricultural Systems, 176*. doi:10.1016/j.agsy.2019.102670

Samsonstuen, S., Åby, B. A., Crosson, P., Beauchemin, K. A., Wetlesen, M. S., Bonesmo, H., & Aass, L. (2020). Variability in greenhouse gas emission intensity of semi-intensive suckler cow beef production systems. *Livestock Science, 239*, 104091. doi:https://doi.org/10.1016/j.livsci.2020.104091

Schleussner, C.-F., Nauels, A., Schaeffer, M., Hare, W., & Rogelj, J. (2019). Inconsistencies when applying novel metrics for emissions accounting to the Paris agreement. *Environmental Research Letters, 14*(12), 124055. doi:10.1088/1748-9326/ab56e7

Seppälä, J., Posch, M., Johansson, M., & Hettelingh, J.-P. (2006). Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicator (14 pp). *The International Journal of Life Cycle Assessment, 11*(6), 403-416. doi:10.1065/lca2005.06.215

Struijs, J., Beusen, A., van Jaarsveld, H. A., & Huijbregts, M. A. J. (2009). Eutrophication. In M. Goedkoop, R. Heijungs, M. Huijbregts, A. De schryver, J. Struijs, & R. van Zelm (Eds.), *Recipe 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition. Report I: Characterisation*. Den Haag, Netherlands: Ministry of Housing, Spatial Planning and Environment (VROM).

TINE. (2021). *Statistikksamling fra Ku- og Geitekontrollen 2021*. Retrieved from https://medlem.tine.no/fag-og-forskning/statistikksamling-for-ku-og-geitekontrollen-2021

Volden, H. (2011). *NorFor-The Nordic feed evaluation system*: EAAP publication no. 130., EAAP - European Federation of Animal Science.

Appendix 1 Data from livestock production

Appendix 1.1 Beef from dairy cattle

Table A1 Average Norwegian farm data for dual-purpose dairy production in 2021 (TINE, 2021) used in the life cycle analysis of dairy beef.

	Unit	Dual-purpose	Reference
Production system			
Cows in Norway	number	213,190	TINE, 2021
Cows in NDHRS	number	192,469	TINE, 2021
Milk delivery	%	94	TINE, 2021
Cows			
Milk yield	kg/LU	8191	TINE, 2021
Fat	%	4.28	TINE, 2021
Protein	%	3.56	TINE, 2021
Lactose	%		
Milk yield	FPCM/LU	8,550	TINE, 2021
Milk yield	ECM/LU	8,673	TINE, 2021
Concentrates, cows	kg/100kg ECM	30	TINE, 2021
Concentrates, cows	MJ/100kg ECM	206	TINE, 2021
First calf heifers	proportion	0.384	TINE, 2021
Lactation number at culling	number	2.7	TINE, 2021
Culled cows, first calf	%	30.3	TINE, 2021
Culled cows, older	%	44.9	TINE, 2021
Calving interval	month	12.4	TINE, 2021
Calves			
Still born calves, bull	%	3.47	TINE, 2021
Still born calves, heifer	%	2.63	TINE, 2021
Calves dead, bull	%	0.6	TINE, 2021
Calves dead, heifer	%	0.7	TINE, 2021
Herd dynamics			
Dairy cows	LU/herd	30.9	TINE, 2021
Heifers, 0–25 months	LU/herd	31.9[a]	-
Bulls, 0 months –slaughter	LU/herd	22.1[a]	-
Age at calving, heifers	month	25.6	TINE, 2021
Age at slaughter, young bulls	days	544	TINE, 2021
Slaughter weight, young bulls	kg carcass	319	TINE, 2021
Carcass production	kg/cow	273[b]	
Feed intake cows[c]			
Concentrate mixture dairy	MJ/LU	17,879	-
Grass silage	MJ/LU	19,571	-
NH_3 straw	MJ/LU	N.A.	-
Straw	MJ/LU	N.A.	-

Grazing, arable land	MJ/LU	1,799	-
Grazing, permanent pasture[d]	MJ/LU	695	-
Grazing, outfield pasture[e]	MJ/LU	295	-

NDHRS= Norwegian Dairy Herd Recording System; LU= livestock units (sum of the number of days over individual animals in the category divided by 365 days); FPCM= fat and protein corrected milk; ECM= energy corrected milk.

[a] Based on herd dynamics, mortality rates, age at culling, age at slaughter, and age at calving.
[b] Calculated based on herd dynamics, carcass delivered to slaughterhouse and number of dairy cows in the Norwegian Dairy Herd Recording System in 2021
[c] Feed intake for dairy cows was obtained using the Nordic feed evaluation system (NorFor; Volden, 2011) through TINE Optifor, including 3% wastage.
[d] Grass and herbs of good feed value on agricultural land with a clear cultural character not suitable for mechanical harvesting. Permanent pastures are normally enclosed by fences
[e] Natural areas with meadows, heath, and moor which does not meet the requirements of permanent pastures with grazing plants spread over larger areas and lower nutritional value per area unit.

Appendix 1.2 Beef from beef cattle

Table A2 Average Norwegian farm data for beef cattle production in 2021 (Animalia, 2021a) used in the life cycle analysis of beef from beef cattle .

	Unit	Beef cattle	Reference
Production system			
Beef cows in Norway	number	112,026	Animalia, 2021
Beef cows in NBHRS	number	85,800	Animalia, 2021
Calves and young stock			
Calving interval	month	12.7	Animalia, 2021
Still born calves	%	3.2	Animalia, 2021
Calves dead<180 days	%	4.1	Animalia, 2021
Twin births	%	2.3	Animalia, 2021
Cows, carcass weight	kg	339	Animalia, 2021
Cows, age at slaughter	month	88.8	Animalia, 2021
Heifers, birth weight	kg LW	40.5	Animalia, 2021
Heifers, weaning weight	kg LW	266	Animalia, 2021
Heifers, yearling weight	kg LW	418	Animalia, 2021
Heifers, carcass weight	kg	236	Animalia, 2021
Heifers, age at slaughter	month	16.9	Animalia, 2021
Young bulls, birth weight	kg LW	43.1	Animalia, 2021
Young bulls, weaning weight	kg LW	294	Animalia, 2021
Young bulls, carcass weight	kg	331	Animalia, 2021
Young bulls, age at slaughter	month	16.7	Animalia, 2021
Farm size and management			
Beef cows	LU/herd	22.2	Animalia, 2021
Calvings	number/herd	22.6	Animalia, 2021

Heifers, birth–calving	LU/herd	23.0[a]	-
Bulls, birth –slaughter	LU/herd	14.9[a]	-
Age at calving, heifers	months	26,4	Animalia, 2021
Carcass production	kg cow^{-1}	305[b]	
Feed intake[c]			
Cows, concentrate	proportion	0.06	-
Cows, time on pasture	proportion	0.25	-
Heifers, concentrate birth-slaughter or calving	proportion	0.14	-
Heifers, time on pasture	proportion	0.31	-
Young bulls, concentrate birth-slaughter	proportion	0.46	-
Young bulls, time on pasture[d]	proportion	0.05	-
Cow, concentrate	MJ/LU	620	-
Cow, grass silage	MJ/LU	5,011	-
Cow, NH_3 straw	MJ/LU	7,756	-
Cow, grazing, arable land	MJ/LU	0	-
Cow, grazing, permanent pasture[e]	MJ/LU	1,168	-
Cow, grazing, outfield pasture[f]	MJ/LU	3,400	-
Heifer, concentrate	MJ/LU	1,816	-
Heifer, grass silage	MJ/LU	6,080	-
Heifer, NH_3 straw	MJ/LU	1,168	-
Heifer, grazing, arable land	MJ/LU	450	-
Heifer, grazing, permanent pasture[e]	MJ/LU	1,870	-
Heifer, grazing, outfield pasture[f]	MJ/LU	1,768	-
Young bull, concentrate	MJ/LU	7,043	-
Young bull, grass silage	MJ/LU	7462	-
Young bull, NH_3 straw	MJ/LU	1,168	-
Young bull, grazing, arable land[d]	MJ/LU	395	-
Young bull, grazing, permanent pasture[de]	MJ/LU	444	-
Young bull, grazing, outfield pasture[df]	MJ/LU	N.A.	-

NBHRS= Norwegian Beef Herd Recording System; LU= livestock units (sum of the number of days over individual animals in the category divided by 365 days); LW= live weight;

[a] Based on herd dynamics, mortality rates, age at culling, age at slaughter, and age at calving.

[b] Calculated based on herd dynamics, carcass delivered to slaughterhouse and number of beef cattle in the Norwegian Beef Herd Recording System in 2021

[c] Feed intake for beef cattle was obtained using the Nordic feed evaluation system (NorFor; Volden, 2011) through TINE Optifor, including 3% wastage.

[d] Young bulls are only on pasture as calves due to regulations in the Norwegian law.

[e] Grass and herbs of good feed value on agricultural land with a clear cultural character not suitable for mechanical harvesting. Permanent pastures are normally enclosed by fences

[f] Natural areas with meadows, heath, and moor which does not meet the requirements of permanent pastures with grazing plants spread over larger areas and lower nutritional value per area unit.

Appendix 1.3 Mutton and lamb

Table A3 Average Norwegian farm data for sheep production in 2021 (Animalia, 2021b) used in the life cycle analysis of mutton and lamb .

	Unit	Sheep	Reference
Production system			
Sheep in Norway	number	932,841	Statistics Norway, 2022[b]
Ewes in NSHRS	number	85,800	Animalia, 2021
Lambs in Norway at fall	number	745,959	Animalia, 2021
Sheep slaughtered	number	521,485	Animalia, 2021
Ewes per herd	number	88.9	Animalia, 2021
Lamb and lambing			
Lambs born per mated ewe	number	2	Animalia, 2021
Lambs born alive per mated ewe	number	1.91	Animalia, 2021
Lambs at fall per mated ewe, excluding bottle lamb	number	1.47	Animalia, 2021
Lambs at fall per mated ewe, including bottle lamb	number	1.58	Animalia, 2021
Still born	%	4.4	Animalia, 2021
Lambs dead before spring pasture	%	3.4	Animalia, 2021
Lambs dead on spring pasture	%	1	Animalia, 2021
Lambs dead on summer pasture	%	4.1	Animalia, 2021
Lambs, birth weight	kg LW	4.8	Animalia, 2021
Lambs, spring weight	kg LW	18.9	Animalia, 2021
Lambs, fall weight	kg LW	43.1	Animalia, 2021
Lambs, carcass weight	kg	19.7	Animalia, 2021
Lambs, age spring weight	days	42	Animalia, 2021
Lambs, age fall weight	days	136	Animalia, 2021
Lambs, age slaughter	days	155	Animalia, 2021
Yield per ewe	kg	63.7	Animalia, 2021
Ewe, carcass weight	kg	31.7	Animalia, 2021
Lambs, wool production	kg/lamb slaughtered	1.1	Norilia, personal communication, May 10, 2023
Ewe, wool production	kg/ewe		Norilia, personal communication, May 10, 2023
Feed intake[a]			
Ewes, concentrate	proprotion	0.12	
Ewes, time on pasture	proprotion	0.58	
Lambs for breeding, concentrate	proportion	0.22	
Lambs for breeding, time on pasture	proprotion	0.58	
Lambs for slaughter, concentrate	proprotion	0.07	
Lambs for slaughter, time on pasture	proprotion	0.74	

NSHRS= Norwegian Sheep Herd Recording System; LW= live weight

[a] Feed intake for sheep and lamb was obtained using the excel model for sheep feeding developend by

Nortura (Nortura sauefôring) in addition to Rekdal & Angeloff (2021) for estimating feed intake during outfield pasture.

[b] Statistics Norway, 2022, count date 1 March table 03803: Winter sheep, by livestock size, statistical variable and year and table 03710: Livestock as of 1 March, by livestock type 1990 - 2022

Appendix 1.4 Pork

Table A4 Average Norwegian farm data for pig production in 2021 and emission factors used in the LCA.

	Unit	Sow	Young pigs	Piglet	Finisher	References
Average daily gain	kg/day			0,598	1,084	(Ingris, 2021)
FEn per kg gain	FEn/kg			1,7	2,69	
Mortality	%			1,0	1,5	
Slaughter weight	kg/animal				84,7	
Enteric fermentation						
Emission factor	kg/animal/year	1,5	1,5	1,5	1,5	(Norwegian Environment Agency, 2022)
Slaughter age	days/ animal	365	355	37,06	84,7	(Ingris, 2021)
Methane emissions from manure						
% VS excreted	VS%	90 %	90 %	90 %	90 %	(Norwegian Environment Agency, 2022)
Bo: Maximum CH4 producing capacity for manure produced by an animal	m3 /kg of VS	0,30	0,30	0,30	0,30	
Methane conversion factor (MCF) for manure management system	MCF manure	0,074	0,147	0,147	0,147	
Direct nitrous oxide emissions from manure storage						
Total N in excreta	kg/animal	24,4	9,7	1,4	3,2	(Karlengen et al., 2012)
Emission factors for direct N_2O emissions from manure management	N_2O-N/kg N excreted	0,01	0	0	0	(Norwegian Environment Agency, 2022)
Indirect nitrous oxide emissions from manure storage						
Ammonium N in excreta	kg/animal	15,3	6,5	0,9	2,1	(EMEP/EEA, 2019)
Unabated emission factors for NH3-N losses from housing	%	24 %	27 %	35 %	27 %	
Abatement measures, housing		100 %	50 %	50 %	50 %	
Temperature correction factor – housing	%	93 %	93 %	93 %	93 %	(Carbon Limits, 2020a)
Amount of bedding	m3 wood chips/ animal	0,6				
Density of bedding material	kg/m3	81,0	81,0	81,0	81,0	

	Unit	Sow	Young pigs	Piglet	Finisher	References
Amount of bedding	kg wood chips/animal	48,600	-	-	4,86	
N in bedding	%	0,25 %	0,25 %	0,25 %	0,25 %	
TAN Immobilisation factor due to bedding	-	0,4	-	-	0,4	
Mineralisation factor (bedding)	-	0	0	0	0	
Emissions of NH_3-N from storage based on the unabated emission factors	%	29 %	11 %	11 %	11 %	
Ammonia reduction potential for abatement measures	%	0 %	60 %	60 %	60 %	(Bittman et al., 2014; Carbon Limits, 2018)
Temperature correction factor – storage	%	85 %	85 %	85 %	85 %	
Emissions factor for NO-N losses from manure storage	EF storage NO	0,01	0,0001	0,0001	0,0001	(Carbon Limits, 2020a)
Emissions factor for N_2 losses from manure storage	EFstorage_N2	0,3	0,003	0,003	0,003	
N_2O emission factor for deposition of N from NH_3 and NOx emissions from housing and storage (indirect N_2O emissions)	kgN_2O-N/kg NH_3-N + NOx-N	0,01	0,01	0,01	0,01	
Fraction for storage systems that are assumed to have leaching	% of storage systems	25 %	0 %	0 %	0 %	
N2O emission factor for leaching/runoff		0,0075	0,0075	0,0075	0,0075	

Appendix 1.5 Chicken

Table A5 Average Norwegian farm data for broiler production in 2021 and emission factors used in the LCA.

	Unit	Parent	Broiler	References
Feed per kg slaughter weight	kg/kg carcass		2,32	(Animalia et al., 2022)
Mortality	%		2,64	
Slaughter weight	kg/animal		1,485	
Slaughter age	days/ animal		37,4	
Methane emissions from manure				
% VS excreted	VS%	90%	90%	
Bo: Maximum CH4 producing capacity for manure produced by an animal	m3 /kg of VS	0,39	0,36	(Norwegian Environment Agency, 2022)
Methane conversion factor (MCF) for manure management system	MCF manure	0,015	0,015	(Carbon Limits, 2020b)
Direct nitrous oxide emissions from manure storage				
Total N in excreta	kg/animal	0,70	0,03	(Norwegian Environment Agency, 2022)
Emission factors for direct N_2O emissions from manure management	N_2O-N/kg N excreted	0,001	0,001	
Indirect nitrous oxide emissions from manure storage				
Ammonium N in excreta	kg/animal	0,3	0,01	(Norwegian Environment Agency, 2022)
Unabated emission factors for NH3-N losses from housing	%	20 %	21 %	
Abatement measures, housing		100 %	100 %	
Temperature correction factor – housing	%	93 %	93 %	
Amount of bedding	m3 wood chips/ animal	0,007	0,005	
Density of bedding material	kg/m3	81,0	81,0	
Amount of bedding	kg wood chips/animal	0,567	0,405	
N in bedding	%	0,25 %	0,25 %	
TAN Immobilisation factor due to bedding	-	0,4	0,4	
Mineralisation factor (bedding)	-	0	0	
Emissions of NH_3-N from storage based on the unabated emission factors	%	8 %	30 %	
Ammonia reduction potential for abatement measures	%	0 %	0 %	
Temperature correction factor – storage	%	85 %	85 %	

	Unit	Parent	Broiler	References
Emissions factor for NO-N losses from manure storage	EF storage NO	0,01	0,01	
Emissions factor for N_2 losses from manure storage	EFstorage_N2	0,3	0,3	
N_2O emission factor for deposition of N from NH_3 and NOx emissions from housing and storage (indirect N_2O emissions)	kgN_2O-N/kg NH_3-N + NOx-N	0,01	0,01	
Fraction for storage systems that are assumed to have leaching	% of storage systems	25 %	25 %	
N2O emission factor for leaching/runoff		0,0075	0,0075	

Appendix 1.6 Turkey

Table A6 Average Norwegian farm data for turkey production in 2021 and emission factors used in the LCA. Other emission factors are similar to those for chicken in table A5.

	Unit	Parent	Turkey portion	Turkey industry	References
Feed per kg slaughter weight	kg/kg carcass		3,04	3,04	(Animalia et al., 2022)
Mortality	%		5,24	5,24	
Slaughter weight	kg/animal		5,484	3,498	
Slaughter age	days/ animal		87	130	
Methane emissions from manure					
% VS excreted	VS%	90%	90%	90%	
Bo: Maximum CH4 producing capacity for manure produced by an animal	m3 /kg of VS	0,36	0,36	0,36	(Norwegian Environment Agency, 2022)
Methane conversion factor (MCF) for manure management system	MCF manure	0,015	0,015	0,015	(Carbon Limits, 2020b)
Direct nitrous oxide emissions from manure storage					
Total N in excreta	kg/animal	0,70	0,05	0,706	(Norwegian Environment Agency, 2022)
Emission factors for direct N_2O emissions from manure management	N_2O-N/kg N excreted	0,001	0,001	0,001	
Indirect nitrous oxide emissions from manure storage					
Ammonium N in excreta	kg/animal	0,287	0,02	0,298	(Norwegian Environment Agency, 2022)
Unabated emission factors for NH3-N losses from housing	%	20 %	21 %	20 %	
Abatement measures, housing		100 %	100 %	100 %	

Appendix 1.7 Egg

Table A7 Average Norwegian farm data for egg production in 2021 and emission factors used in the LCA. Other emission factors are similar to those for chicken in table A5.

	Unit	Parent	Pullet	Laying hen	References
Feed per kg egg	kg/kg carcass			2,05	(Animalia et al., 2022)
Mortality	%			3,93	
Egg weight	kg/animal			22,7	
Methane emissions from manure					
% VS excreted	VS%	90%	90%	90%	
Bo: Maximum CH4 producing capacity for manure produced by an animal	m3 /kg of VS	0,36	0,36	0,36	(Norwegian Environment Agency, 2022)
Methane conversion factor (MCF) for manure management system	MCF manure	0,015	0,015	0,015	(Carbon Limits, 2020b)
Direct nitrous oxide emissions from manure storage					
Total N in excreta	kg/animal	2,0	0,5	0,75	(Norwegian Environment Agency, 2022)
Emission factors for direct N_2O emissions from manure management	N_2O-N/kg N excreted	0,001	0,001	0,001	
Indirect nitrous oxide emissions from manure storage					
Ammonium N in excreta	kg/animal	0,8	0,2	0,3	(Norwegian Environment Agency, 2022)
Unabated emission factors for NH3-N losses from housing	%	35 %	35 %	35 %	
Abatement measures, housing		100 %		100 %	

NORSUS
Norwegian Institute for
Sustainability Research

The vision of NORSUS Norwegian Institute for Sustainability Research (formerly Ostfold Research) is to provide knowledge for sustainable societal development. We apply and develop knowledge and methods to understand and implement sustainable solutions in society. Together with a wide range of public and private clients, we undertake projects locally, nationally and internationally to enhance environmental performance, often also generating economic benefits.

WEBSITE	E-MAIL	ORG.NO.	ADDRESS
www.norsus.no	post@norsus.no	989 861 751 MVA	Stadion 4, N-1671 Kråkerøy