Life Cycle Assessment of meat and egg - Nortura

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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, 1 kg consumer product, 1 kg edible meat and 1 kg protein from beef from dairy cattle, beef from beef cattle, mutton and lamb, pork, turkey, chicken, and similarly for egg. The environmental impact of meat and egg produced in Norway is based on average production levels in Norway.

The table below shows the total environmental impacts at industry gate of Nortura for all animal species per kg carcass and egg and greenhouse gas emissions (GHG) per kg of protein.

Total environmental impacts from cradle to slaughterhouse gate per kg carcass, kg egg and GHG per kg of protein

Impact category and unit	Beef dairy cattle	Beef beef cattle	Mutton and lamb	Pork	Chicken	Turkey	Egg
Per kg of carcass and egg							
GHG total (kg CO_2 eqv)	21.6	30.0	23.0	3.4	2.3	2.3	1.5
- GHG methane (kg CO_2 eqv)	*10.2*	*16.3*	*10.2*	*0.7*	*0.1*	*0.2*	*0.1*
-GHG, nitrous oxide (kg CO_2 eqv)	*7.2*	*10.5*	*9.9*	*0.6*	*0.4*	*0.7*	*0.4*
-GHG fossil (kg CO_2 eqv)	*3.5*	*2.8*	*2.3*	*1.6*	*1.5*	*1.3*	*0.9*
-GHG LULUC (kg CO_2 eqv)	*0.3*	*0.1*	*0.07*	*0.04*	*0.04*	*0.07*	*0.05*
Land occupation, excl. outfields (m^2)	26.6	27.6	23.0	6.5	4.4	6.3	3.6
Biodiversity (PDF)	7.0	-14	-38	4.3	2.9	4.1	2.4
Eutrophication, marine (kg N eqv)	0.05	0.04	0.05	0.01	0.01	0.01	0.01
Eutrophication, freshwater (kg P eqv)	0.014	0.011	0.009	0.0009	0.0006	0.0006	0.0004
Eutrophication, terrestrial (mol N eqv)	1.85	2.50	1.53	0.22	0.12	0.36	0.12
Particulate matter (disease inc.)	2.7E-06	3.8E-06	2.0E-06	4.0E-07	2.0E-07	6.0E-07	2.0E-07
Acidification (mol H+ eqv)	0.41	0.56	0.33	0.05	0.03	0.08	0.03
Water scarcity (m^3 depriv.)	1.8	0.6	0.7	0.5	2.1	1.8	1.4
GHG per kg of protein (kg CO_2 eqv)	187	259	258	24	19	18	12

For the ruminants dairy cattle, beef cattle and sheep, a large part of the GHG emissions arises from enteric methane (CH_4). A large part also comes from nitrous oxide (N_2O) from housing and manure storage. For the monogastric animals pig, chicken, turkey and laying hen, nitrous oxide 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 nitrous oxide 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 from permanent pasture, 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 scarcity are mainly driven by feed production. In particular, poultry feed contains imported feed ingredients which impact water use due to the AWARE (Available WAter Remaining) method. This method regionalizes characterization factors by considering the water availability in each specific country.

The results for meat in this study are calculated per kg carcass, kg consumer products, kg edible (boneless) meat and per kg protein. The total environmental burdens from the carcass are distributed to meat, by-products and hides and skins by using economic allocation factors. For consumer products, specific allocation factors for Nortura are used, based on the total quantity and economic value for each animal species. For edible meat, default allocation factors are provided by PEF and are used for beef, pork, mutton and lamb. The environmental impacts per kg of protein were based on the average protein content in edible meat.

The results document the environmental impact of current livestock production and includes several impact categories such as climate change, land occupation, biodiversity, eutrophication, particulate matter. They provide a foundation 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 – Sustainable Livestock Production* (grant no. 295189). 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 industry gate of Nortura, see Figure 2.1. Each livestock system included rearing of the parent generation and young animals until slaughter.

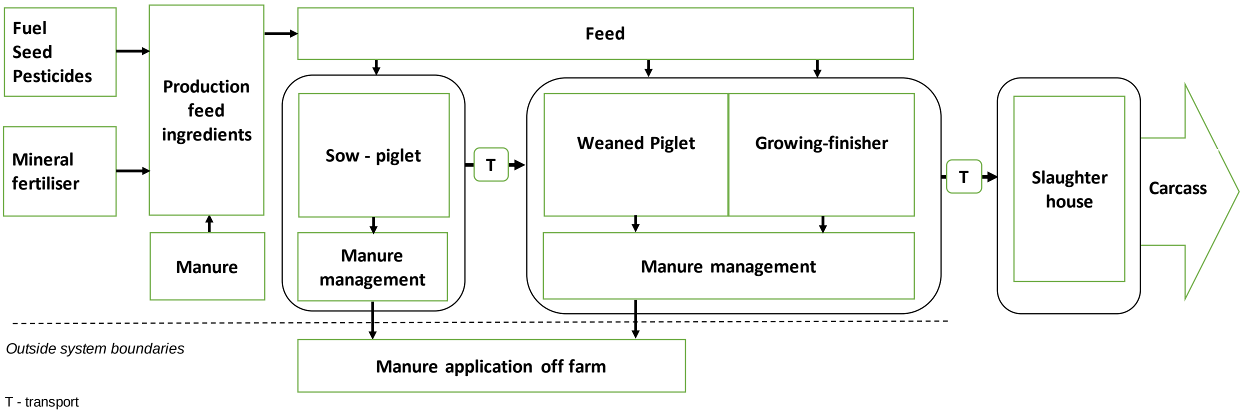

Figure 2.1 General system description for the pig production system. Similar system boundaries are used for beef from dairy cattle, beef from beef cattle, mutton and lamb, pork, turkey, chicken, and egg.

2.2 Functional unit

The functional units were defined as 1 kg carcass, 1 kg consumer product, 1 kg edible meat and 1 kg protein from beef from dairy cattle, beef from beef cattle, mutton and lamb, pork, turkey, chicken and includes cradle to gate of Nortura slaughterhouse or egg packing and processing plant.

2.3 Allocation

Allocation means distributing the emissions and environmental impacts from a process between several outputs. The choice of allocation principles follows these steps. First, if allocation cannot be avoided by dividing the unit process into two or more sub-processes, the inflows and outflows must be allocated based on the underlying physical relationships. This means that they should reflect how activities in the process affect the outflows delivered by the system. Where physical relationship cannot be established or used as the basis for allocation, the input should be allocated between the products and the functions in a way that reflects other relationships between them. For example, inputs and output data might be allocated between co-products in proportion to the economic value of the products.

The choice of allocation method in this study was based on recommendations in the PEFCR (Product Environmental Footprint Category Rules*)*. For feed and plant production, economic allocation has been used for co-products on the farm (e.g., rapeseed oil and rapeseed meal) and followed the PEFCR for feed (FEFAC, 2018).

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

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

Allocation factor meat = 1 ÷ Allocation factor milk

where M_{meat} is the mass of live weight of all animals sold including bull calves and culled mature animals per year, and M_{milk} is the mass of fat and protein corrected milk (FPCM) sold per year (corrected to 4% fat and 3.3% protein). Based on the average farm data, the biophysical allocation factor is 40% for beef and 60% for milk.

Allocation between sheep and wool shall according to PEF (Product Environmental Footprint) be based on a biophysical relationship using energy requirements. The net energy requirements for growth and wool in sheep production were calculated based on standard equations (European Commission, 2018, 2021; IPCC et al., 2006; NRC, 2007). Based on the average farm data used in this study, the biophysical allocation factor at farm level was 78% for sheep and 22% for wool (see appendix 1.3). Biophysical allocation at farm level was applied for all wool produced, although this was not the actual distribution. In Norway, the wool at farm level account for 70% of the total wool volume, while the remaining 30% comes from shearing of sheep and lambs at the slaughterhouse. This was not taken into account, however, as allocation in this study was performed in accordance to PEF. (European Commission, 2021).

At the slaughterhouse, economic allocation according to PEF shall be used for distribution of environmental impacts between meat, by-products and hides and skins. To calculate the environmental impacts of the product mix sold by Nortura, i.e. consumer products which includes fresh meat and processed products (some containing a proportion of bones like chops and ribs), specific allocation factors for Nortura have been applied (Table 2.1). These allocation factors are calculated based on the total quantity and economic value of consumer products, by-products and hides and skins. The economic values are derived from the wholesale prices, set by Nortura as market regulator, which are the basis for calculating the settlement prices for farmers. These prices are not the actual prices when delivered to the market, but are the best available divided by animal type. For fresh edible meat including edible offal, the standard allocation factors given by PEF for beef, pork, mutton and lamb (European Commission, 2021) were used as a proxy (Table 2.1).

Variations in the allocation ratio for each animal species are explained by the differences between consumer products and fresh edible meat.

Table 2.1 Allocation factors, mass fraction and allocation ratio for beef, mutton and lamb, pork, chicken and turkey. Values for specific data from Nortura and default values from PEF are included.

		Economic allocation (%)	Mass fraction (%)	Allocation ratio
Beef	Nortura	97.2	53	1.84
	PEF	92.9	49	1.90
Mutton and lamb	Nortura	98.2	54	1.81
	PEF	97.8	44	2.22
Pork	Nortura	99.1	69	1.44
	PEF	98.7	67	1.47*
Chicken	Nortura	99.1	63	1.57
Turkey	Nortura	99.7	66	1.51

* *The allocation ratio for pork is calculated by economic allocation divided by mass fraction. This result deviates from the value in the PEF document.*

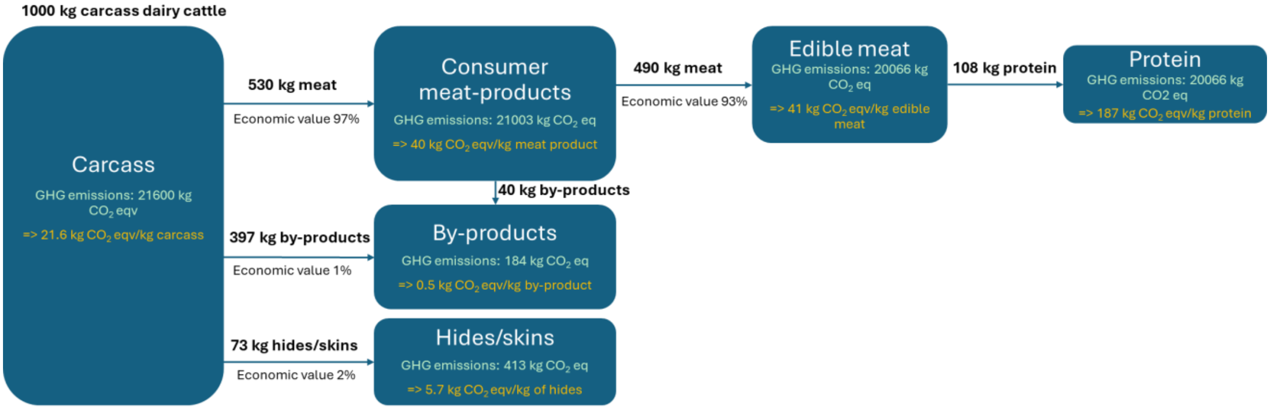

Figure 2.2 Example of allocation of GHG emissions for 1000 kg of beef carcass from dairy cattle divided into consumer meat product, by-products and hides. In addition, the allocation to edible meat and its protein content.

As the meat product is refined, its nutritional content becomes more concentrated and the market value increases. However, this concentration also leads to a reduction in overall quantity, see Figure 2.2. When the carcass is processed, a large portion of the weight is removed as lower-value by-products (e.g., bones and other non-edible parts). In addition, most of the environmental impacts are allocated to the meat (Table 2.1). As a result, the final product represents a smaller fraction of the original carcass weight. When environmental impacts are calculated per kg of product, e.g. as boneless meat or protein, that impact will be higher than per kg of the original carcass, because it represents a smaller fraction of the total.

In chapter 3, the environmental impacts are presented per kg of carcass, per consumer product and per kg meat and kg edible offal. In addition, the results were also presented as impacts per kg of protein. This was based on the average protein content in meat and edible offal.

Table 2.2 Average protein content of meat and edible offal (based on data from matvaretabellen)

	Average protein content (g/kg)
Beef	220
Mutton and lamb	198
Pork	210
Chicken and turkey	191
Egg	130

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 2.3. Direct dinitrogen 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.

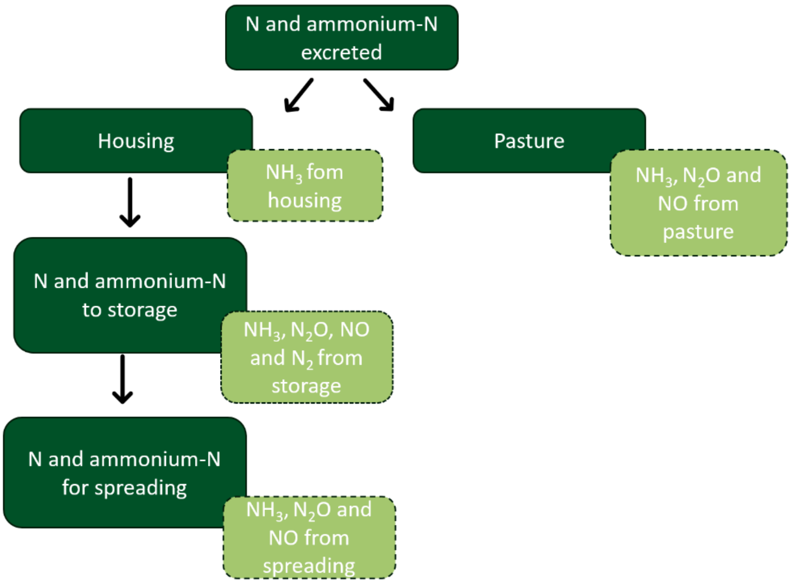

Figure 2.3 Simplified overview over the step-wise calculation of atmospheric nitrogen emission from housing and manure storage based on Carbon Limits (2020a).

2.5 Impact categories

When deciding which environmental impact categories to include in an analysis, it is crucial to consider the most significant aspects of the system under study. Various approaches can be employed to select impact categories. One approach involves reviewing research to identify key dimensions, such as planetary boundaries or studies of similar systems. Another approach is to use weighting methods to prioritize impact categories that represent the largest share of the total environmental impact. However, this assumes that the chosen weighting method includes all critical impact categories. In this study the following environmental impacts were included: Climate change, land occupation, biodiversity loss, eutrophication, particulate matter, acidification, and water scarcity. The selection of the impact categories was based on PEFCR for dairy product and PEFCR for feed for food producing animal (European Dairy Association, 2018; FEFAC, 2018). Biodiversity loss was included in addition to the recommendation in the PEFCRs. Because there was no comprehensive biodiversity approach in LCA, that accounts for the biodiversity loss, a simplified approach was used in this study, see 2.5.3

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 is 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 characterization factors from IPCC 2021 are used in the analysis.

The on-farm GHG emissions included direct emissions of methane (CH_4), nitrous oxide (dinitrogen monoxide 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

There are several drivers for the loss of biodiversity, e.g. land use, climate change, pollution and invasive alien species. Quantification of biological diversity is therefore complex. Several methods have been developed within LCA, but many of these have insufficient characterization factors. The method used in this study only includes impacts from land use and provides an estimate for loss of biodiversity.

Biodiversity impact was assessed for land use 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 management situation. In this study, the PDF values per m^2 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. Figure 2.4 shows an example of PDF per m^2 for three different cattle production systems based on results from Mogensen et al. (2015) of which the extensive system has the largest negative value, thereby contributing to increased biodiversity.

Table 2.3 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

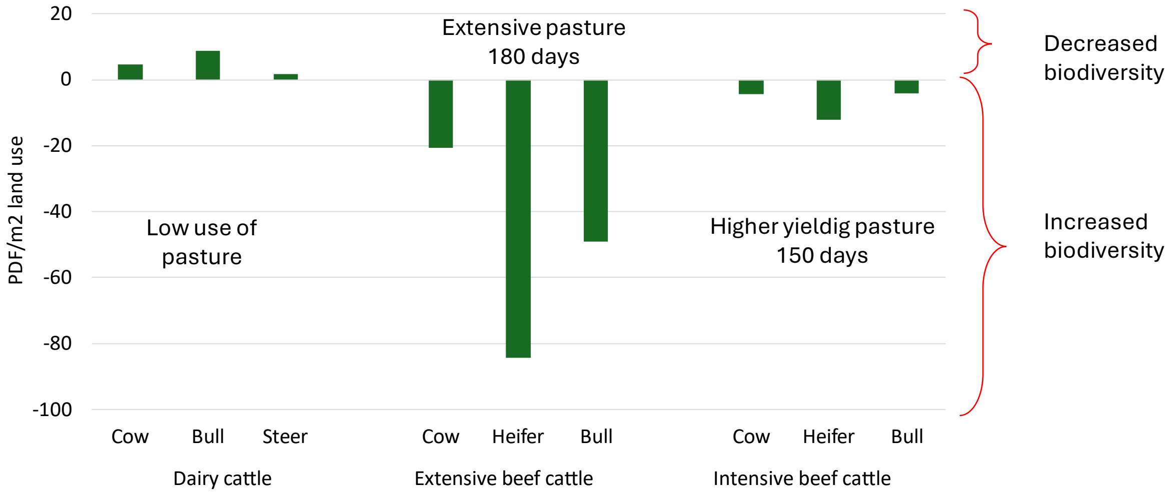

Figure 2.4 Example of potential disappeared fraction (PDF)/m2 land use for three different cattle production systems based on Mogensen et al. (2015).

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 scarcity

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). Calculations of the water scarcity category are closely linked to country-specific characterization factors and thus which country feed ingredients come from. Since the country of origin for the various feed ingredients varies widely over time, the results have great uncertainty and must be regarded as estimates.

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; Kjos 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 (Kjos 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 tonnes 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 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 2.5), 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.

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

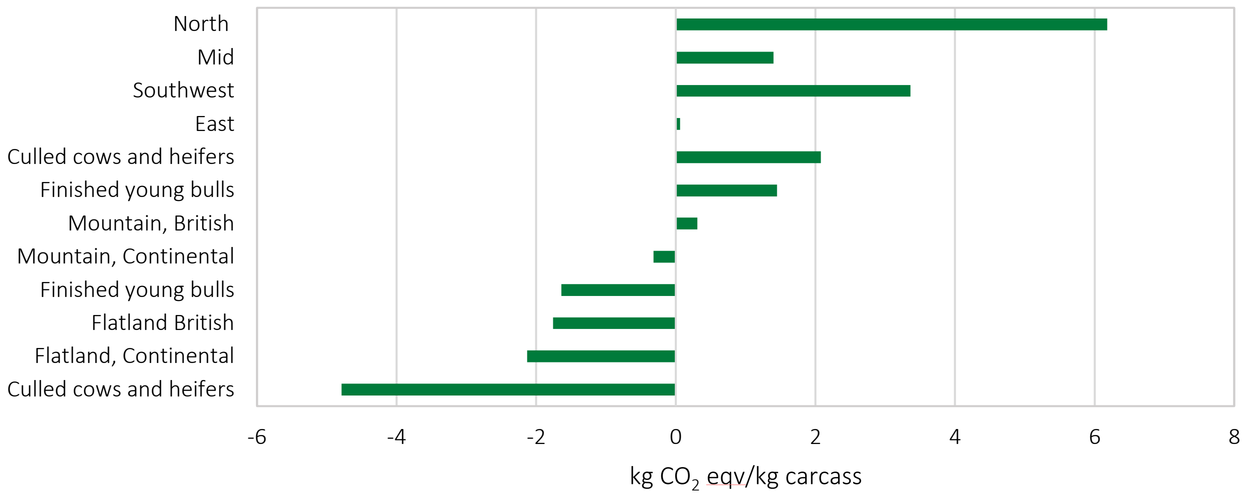

Figure 2.5 Carbon sequestration or carbon loss associated with beef production in Norway, measured in kg of carbon dioxide equivalents per kg of carcass weight. Negative values mean sequestration (removal of C from the air) and positive values means carbon loss (emissions of C to the air). Values are 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 of dairy cattle, including heifers and bulls, are provided in Table 3.1. Detailed results for each environmental impact throughout the life cycle up to slaughterhouse gate, are shown in the following figures. Conversion from carcass to consumer product and meat and protein is based on factors in Table 2.1 and Table 2.2.

Table 3.1 Total environmental impacts of dairy cattle per kg of carcass, consumer product, edible meat and protein.

Impact category and unit	**Impacts per kg of carcass**	**Impact per kg consumer product**	**Impacts per kg of edible meat**	**Impacts per kg of protein**
GHG, total (kg CO_2 eqv)	21.6	39.8	41.1	187
GHG, methane biogenic (kg CO_2 eqv)	*10.2*	*18.7*	*19.3*	*88*
GHG, nitrous oxide (kg CO_2 eqv)	*7.2*	*13.2*	*13.6*	*62*
GHG, carbon dioxide, fossil (kg CO_2 eqv)	*3.5*	*6.4*	*6.7*	*30*
GHG, carbon dioxide, Land Use Change (kg CO_2 eqv)	*0.3*	*0.5*	*0.6*	*2.5*
GHG, other greenhouse gases (kg CO_2 eqv)	*0.5*	*0.9*	*0.9*	*4.3*
Land occupation, excl. outfields (m^2)	27	49	51	230
Biodiversity (PDF)	7.0	13	13	60
Eutrophication, marine (kg N eqv)	0.05	0.10	0.10	0.46
Eutrophication, freshwater (kg P eqv)	0.014	0.026	0.026	0.12
Eutrophication, terrestrial (mol N eqv)	1.9	3.4	3.5	16
Particulate matter (disease inc.)	2.7E-06	5.0E-06	5.2E-06	2.4E-05
Acidification (mol H+ eqv)	0.41	0.75	0.78	3.54
Water scarcity, deprivation-weighted (m^3 depriv.)	1.8	3.3	3.4	16

3.1.1 Climate change

The GHG emissions from dairy cattle is shown in Figure 3.1. 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 3.1 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 and 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.

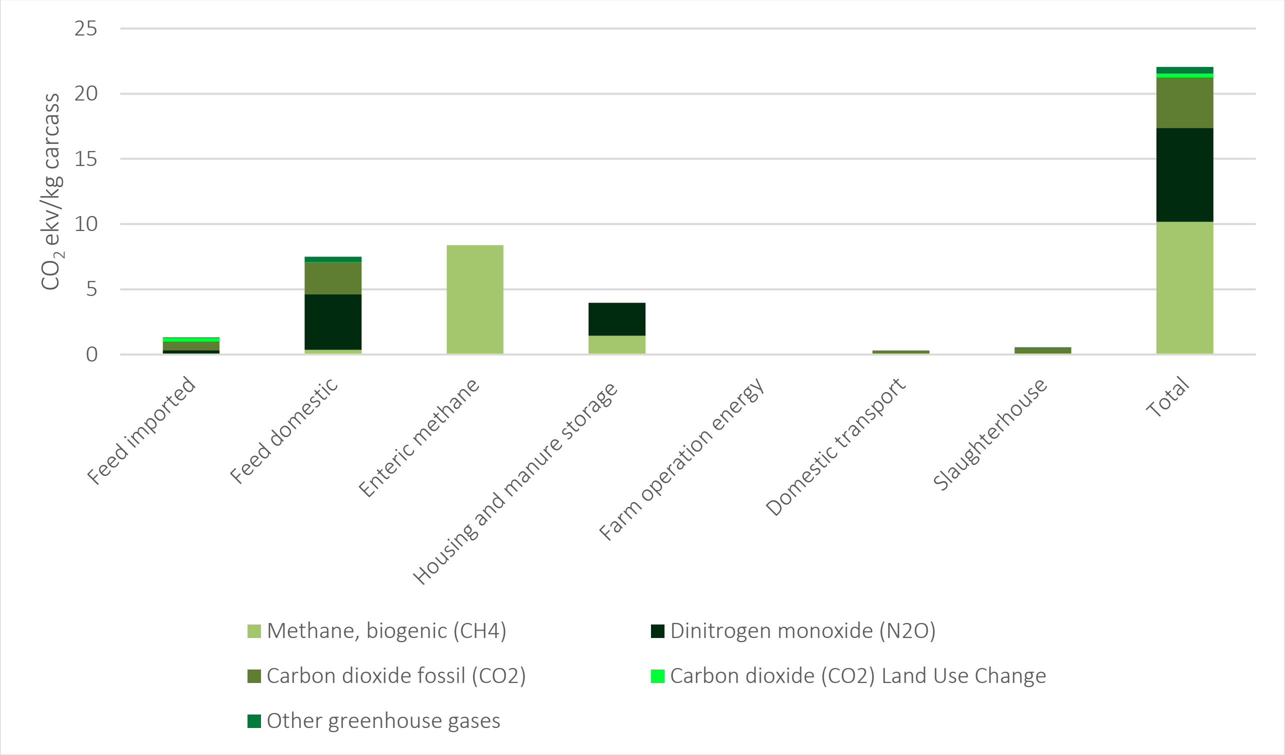

Figure 3.1 Climate change (CO_2 eqv.) per kg carcass through the life cycle (cradle to the gate of the slaughterhouse) of beef from dairy cattle.

3.1.2 Land occupation

Land occupation for production of feed is shown in Figure 3.2, 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%).

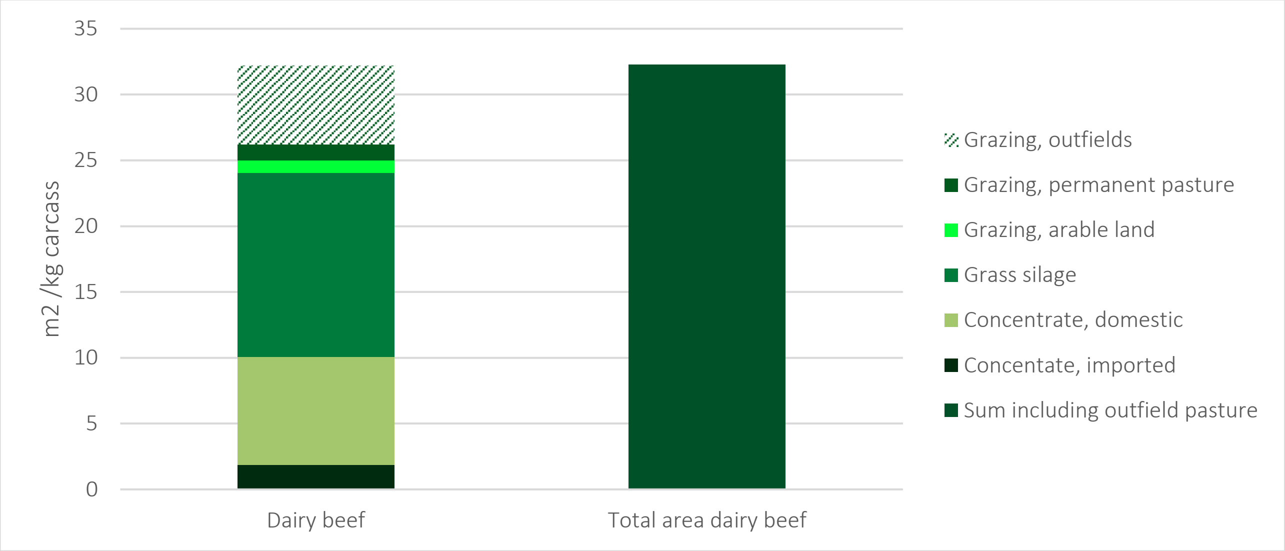

Figure 3.2 Land occupation (m^2) distributed by land category per kg carcass of dairy cattle through the life cycle (cradle to the gate of the slaughterhouse).

3.1.3 Biodiversity

Loss of biodiversity linked to land use for feed production is shown in Figure 3.3, 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 situation of semi-natural woodlands. The column on the right in figure shows the net loss of biodiversity as PDF.

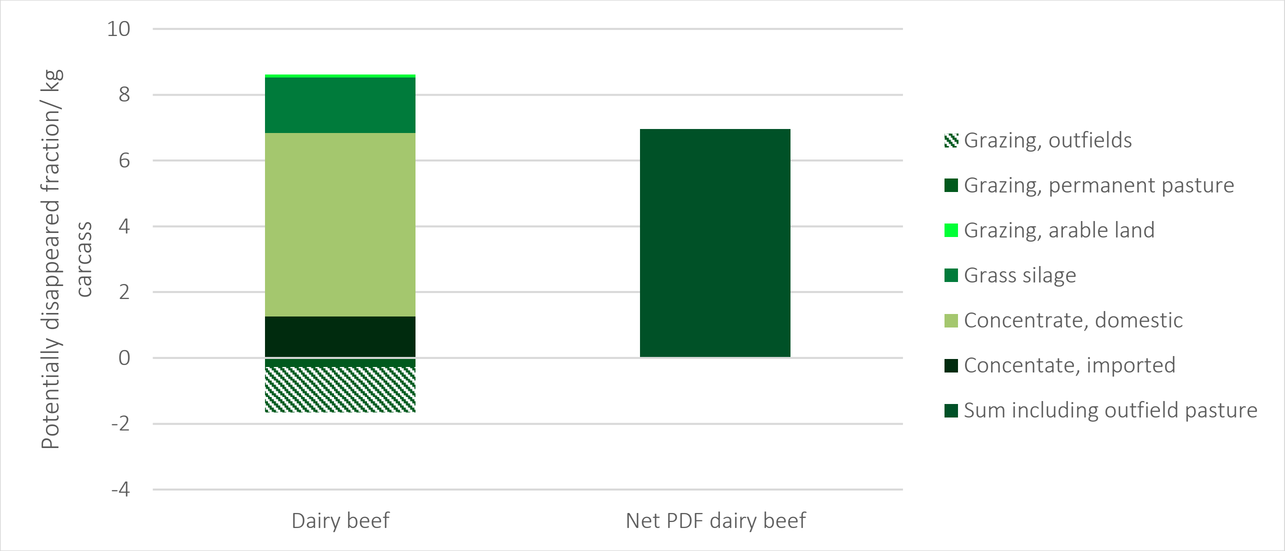

Figure 3.3 Biodiversity as potential disappeared fraction (PDF; Knudsen et al., 2017) per kg carcass of dairy cattle.

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 3.4 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.

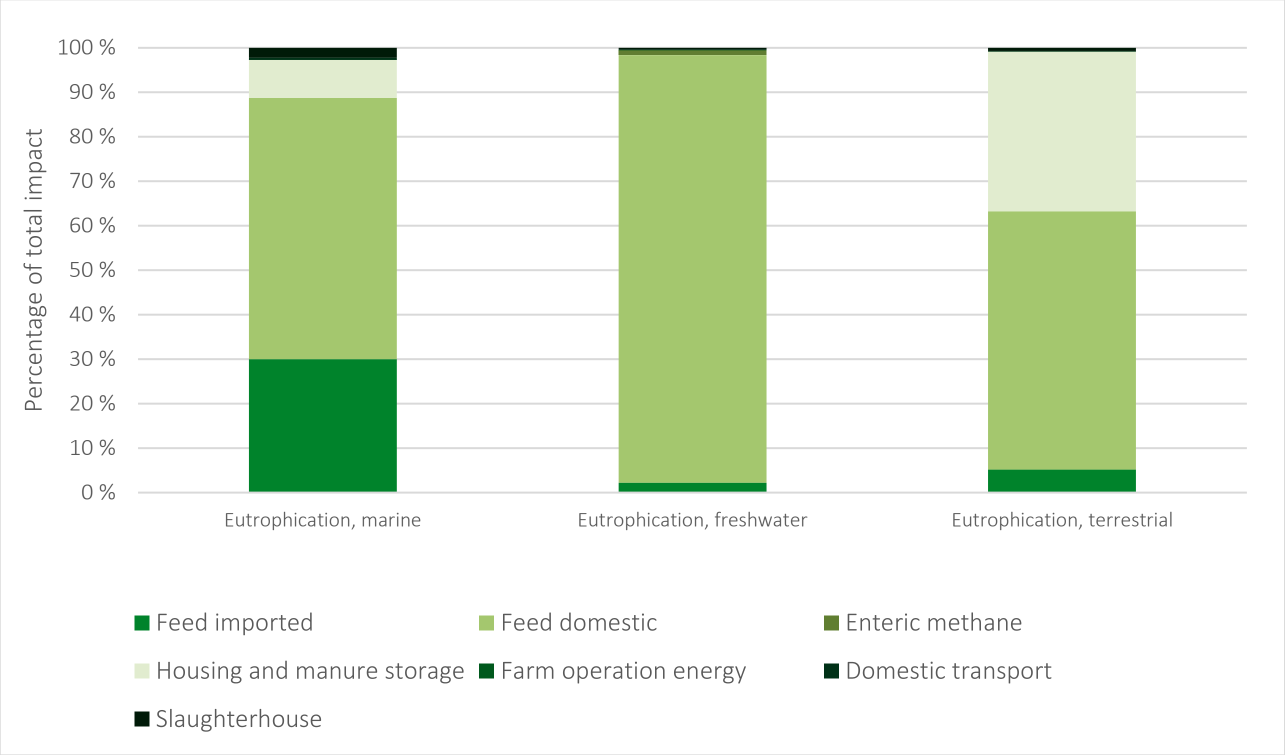

Figure 3.4 Marine eutrophication, freshwater eutrophication and terrestrial eutrophication per kg carcass of dairy cattle through the life cycle (cradle to the gate of the slaughterhouse) as percentage of total impact for each category.

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 3.5 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.

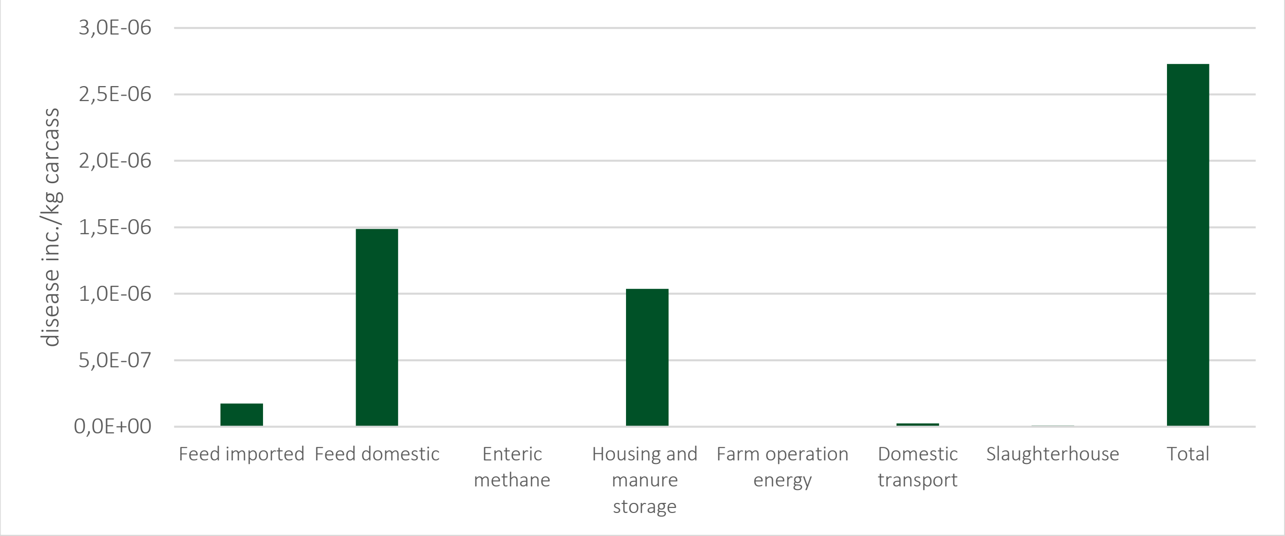

Figure 3.5 Particulate matter (disease inc.) per kg carcass of dairy cattle through the life cycle (cradle to the gate of the slaughterhouse).

3.1.6 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 3.6, 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%).

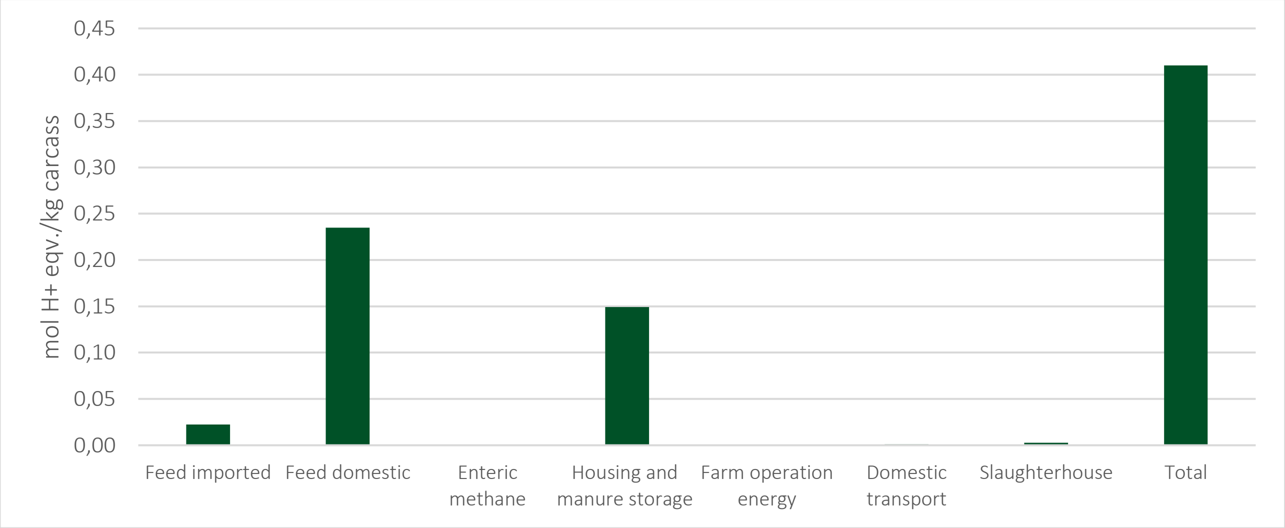

Figure 3.6 Acidification (mol H^+ eqv.) per kg carcass of dairy cattle through the life cycle (cradle to the gate of the slaughterhouse).

3.1.7 Water scarcity

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 scarcity 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 3.7 shows that the imported feed has the largest water scarcity (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.

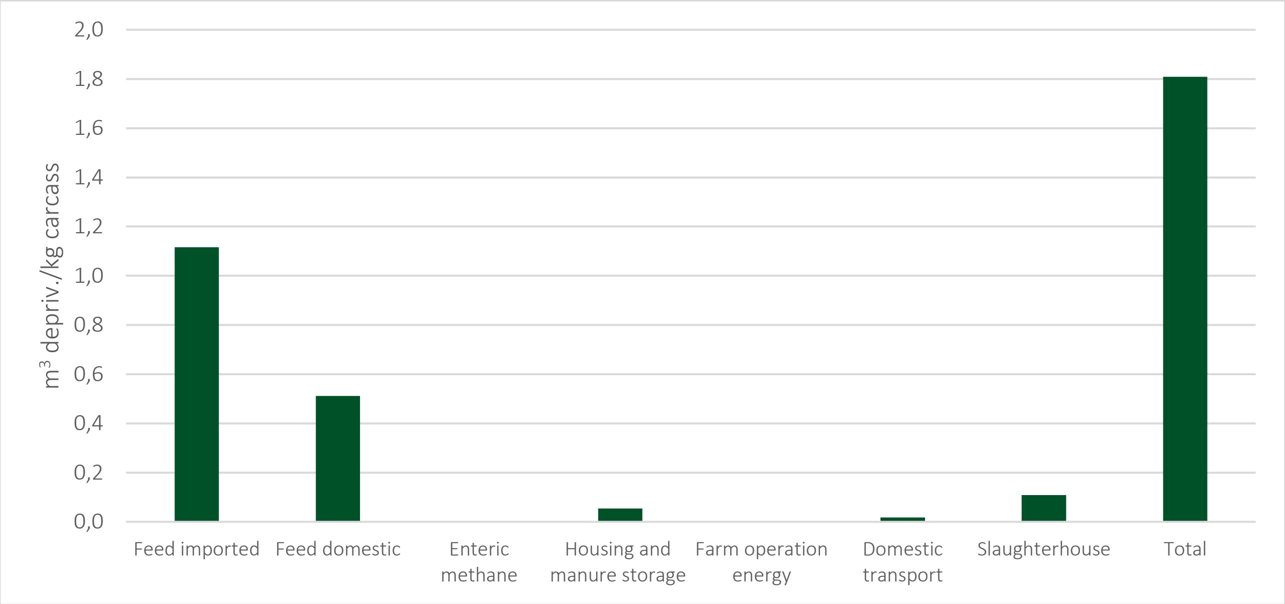

Figure 3.7 Water scarcity (m^3 depriv.) per kg carcass of beef from dairy cattle through the life cycle (cradle to slaughterhouse gate).

3.2 Beef from beef cattle

The total environmental impacts of beef cattle are provided in Table 3.2. Detailed results for each environmental impact throughout the life cycle up to slaughterhouse gate, are shown in the following figures. Conversion from carcass to consumer product and meat and protein is based on factors in Table 2.1 and Table 2.2.

Table 3.2 Total environmental impacts from beef cattle per kg of carcass, consumer product, edible meat and protein.

Impact category and unit	**Impacts per kg of carcass**	**Impact per kg consumer product**	**Impacts per kg of edible meat**	**Impacts per kg of protein**
GHG, total (kg CO_2 eqv)	30.0	55.2	57.0	259
GHG, methane biogenic (kg CO_2 eqv)	*16.3*	*30.0*	*31.0*	*141*
GHG, nitrous oxide (kg CO_2 eqv)	*10.5*	*19.3*	*19.9*	*90*
GHG, carbon dioxide, fossil (kg CO_2 eqv)	*2.8*	5.3	5.5	25
GHG, carbon dioxide, Land Use Change (kg CO_2 eqv)	*0.1*	*0.2*	*0.2*	*0.9*
GHG, other greenhouse gases (kg CO_2 eqv)	*0.3*	*0.5*	*0.5*	*2.4*
Land occupation, excl. outfields (m^2)	28	51	52	238
Biodiversity (PDF)	-14	-25	-26	-118
Eutrophication, marine (kg N eqv)	0.04	0.08	0.08	0.36
Eutrophication, freshwater (kg P eqv)	0.011	0.021	0.022	0.098
Eutrophication, terrestrial (mol N eqv)	2.5	4.6	4.8	21.6
Particulate matter (disease inc.)	3.8E-06	7.0E-06	7.2E-06	3.3E-05
Acidification (mol H+ eqv)	0.56	1.03	1.06	4.81
Water scarcity, deprivation-weighted (m^3 depriv.)	0.6	1.1	1.1	5.0

3.2.1 Climate change

The GHG emissions from beef cattle is shown in Figure 3.8. 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 3.8 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.

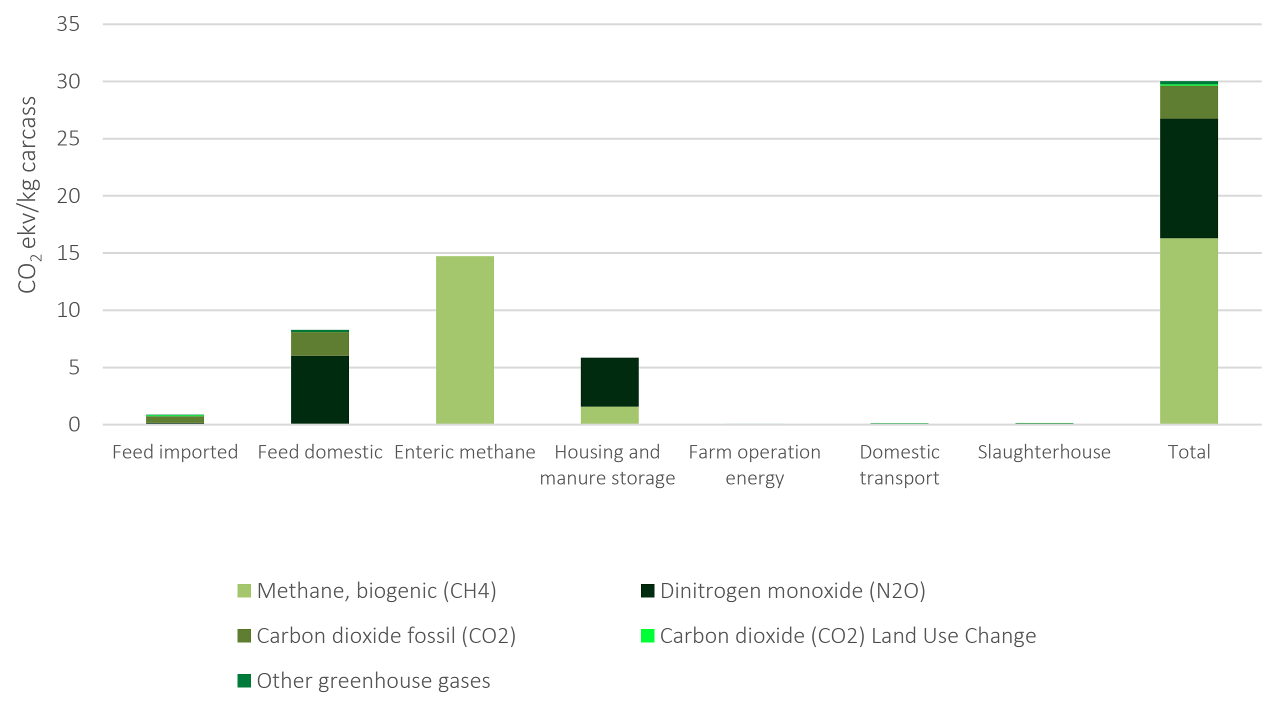

Figure 3.8 Climate change (CO_2 eqv.) per kg carcass through the life cycle (cradle to the slaughterhouse gate) of beef from beef cattle.

3.2.2 Land occupation

Land occupation for production of feed is shown in Figure 3.9, 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.

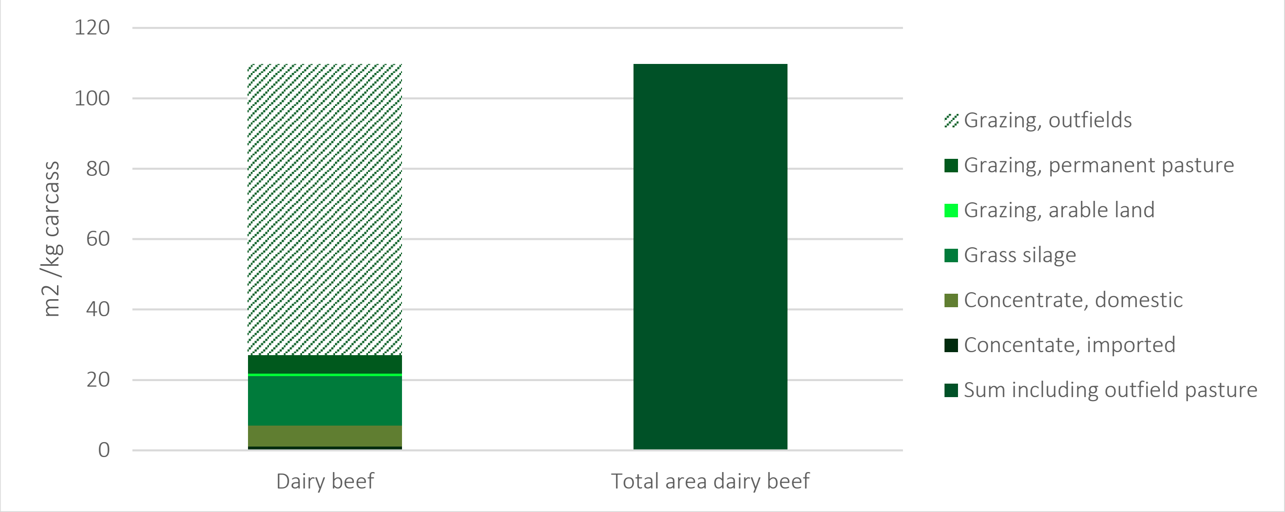

Figure 3.9 Land occupation (m^2) distributed by land category per kg carcass of beef from beef cattle through the life cycle (cradle to the slaughterhouse gate).

3.2.3 Biodiversity

Loss of biodiversity linked to land for feed production is shown in Figure 3.10, 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.

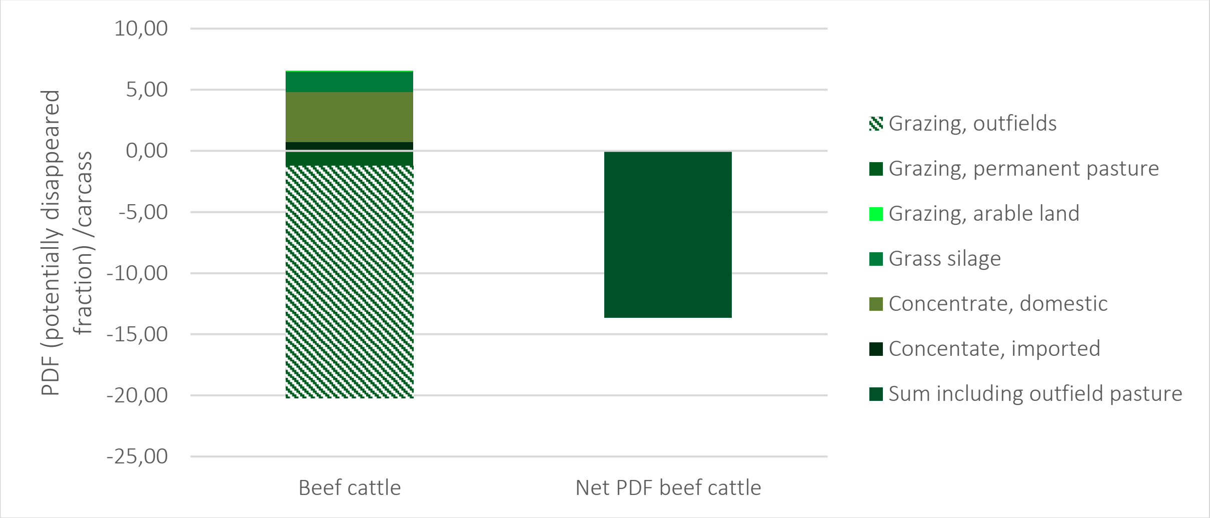

Figure 3.10 Biodiversity as potential disappeared fraction (PDF; Knudsen et al., 2017) per kg carcass of beef from beef cattle

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 3.11 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.

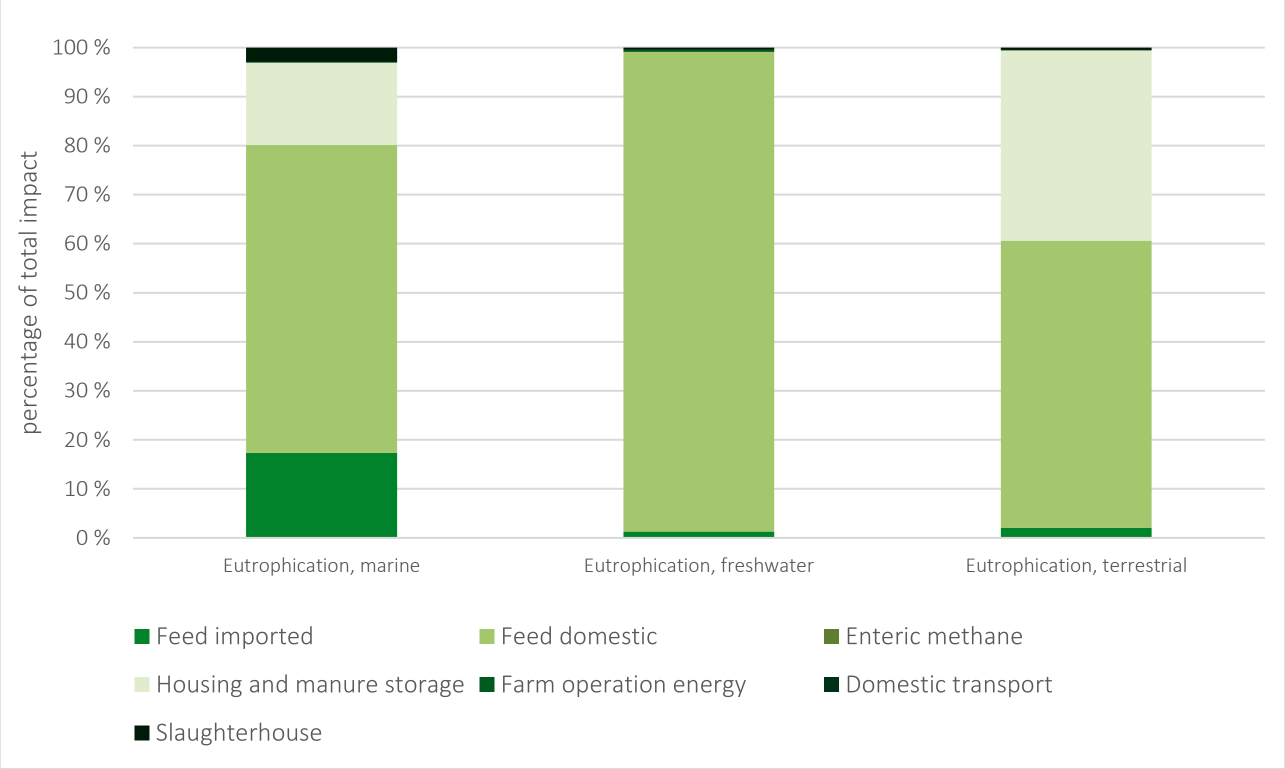

Figure 3.11 Marine eutrophication, freshwater eutrophication and terrestrial eutrophication per kg carcass of beef from beef cattle through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category.

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 3.12 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.

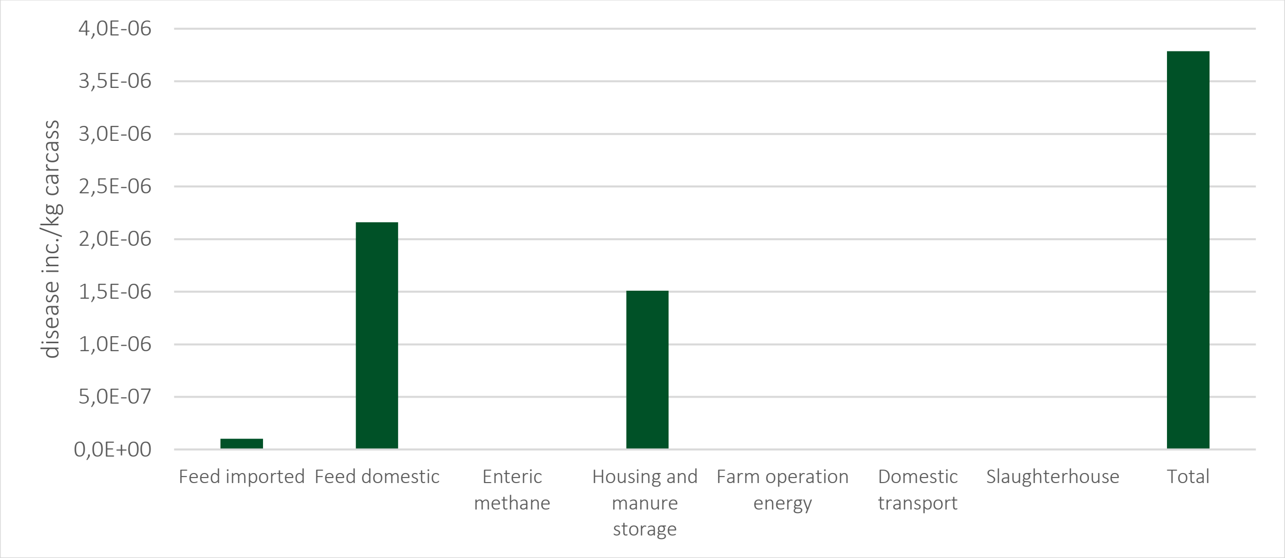

Figure 3.12 Particulate matter (disease inc.) per kg carcass of beef from beef cattle through the life cycle (cradle to slaughterhouse gate).

3.2.6 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 3.13, 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%).

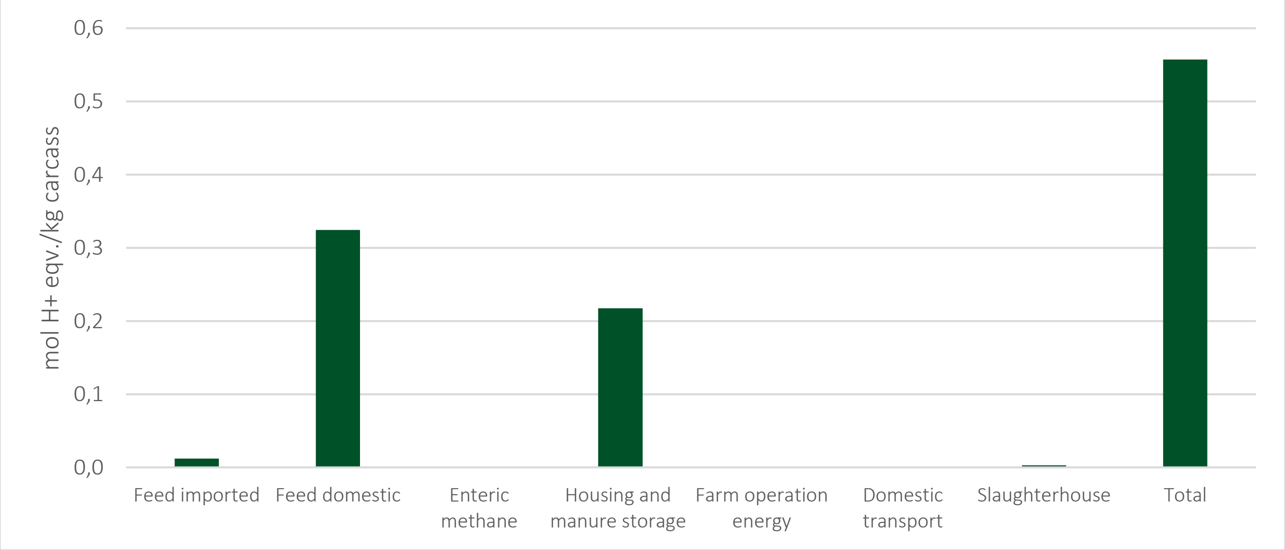

Figure 3.13 Acidification (mol H^+ eqv.) per kg carcass of beef from beef cattle through the life cycle (cradle to slaughterhouse gate).

3.2.7 Water scarcity

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 3.14 shows that the domestic feed imported feed has the largest water scarcity (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.

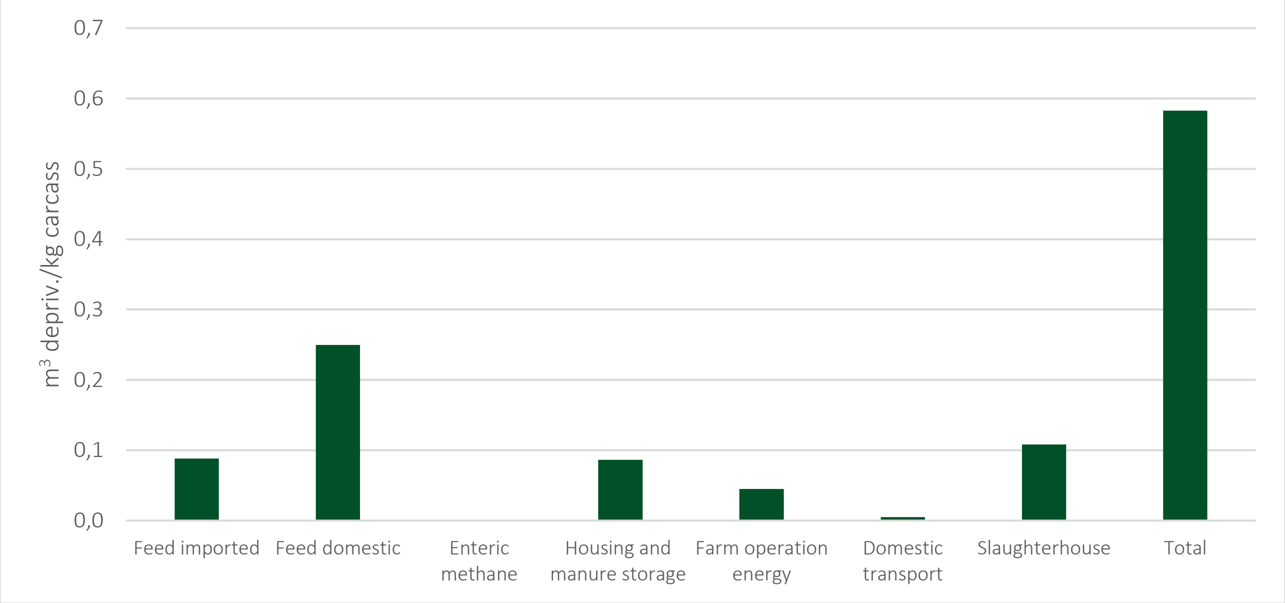

Figure 3.14 Water scarcity (m^3 depriv.) per kg carcass of beef from beef cattle through the life cycle (cradle to slaughterhouse gate).

3.3 Mutton and lamb

The total environmental impacts of sheep and lamb are provided in Table 3.3. Detailed results for each environmental impact throughout the life cycle are shown in the following figures. Conversion from carcass to consumer product and meat and protein is based on factors in Table 2.1 and Table 2.2.

Table 3.3 Total environmental impacts of sheep and lamb per kg of carcass, consumer product, edible meat and protein.

Impact category and unit	**Impacts per kg of carcass**	**Impact per kg consumer product**	**Impacts per kg of edible meat**	**Impacts per kg of protein**
GHG, total (kg CO_2 eqv)	23.0	41.6	51.0	258
GHG, methane biogenic (kg CO_2 eqv)	*10.2*	*18.4*	*22.6*	*114*
GHG, nitrous oxide (kg CO_2 eqv)	*9.9*	*17.9*	*21.9*	*111*
GHG, carbon dioxide, fossil (kg CO_2 eqv)	*2.3*	*4.4*	*5.4*	*27*
GHG, carbon dioxide, Land Use Change (kg CO_2 eqv)	*0.07*	*0.13*	*0.16*	*0.8*
GHG, other greenhouse gases (kg CO_2 eqv)	*0.5*	*0.8*	*1.0*	*5.1*
Land occupation, excl. outfields (m^2)	23	42	51	258
Biodiversity (PDF)	-38	-69	-84	-425
Eutrophication, marine (kg N eqv)	0.05	0.09	0.11	0.58
Eutrophication, freshwater (kg P eqv)	0.009	0.02	0.02	0.10
Eutrophication, terrestrial (mol N eqv)	1.5	2.8	3.4	17
Particulate matter (disease inc.)	2.0E-06	3.7E-06	4.5E-06	2.3E-05
Acidification (mol H+ eqv)	0.33	0.60	0.73	3.7
Water scarcity, deprivation-weighted (m^3 depriv.)	0.7	1.3	1.6	8.0

3.3.1 Climate change

The GHG emissions from sheep and lamb is shown in

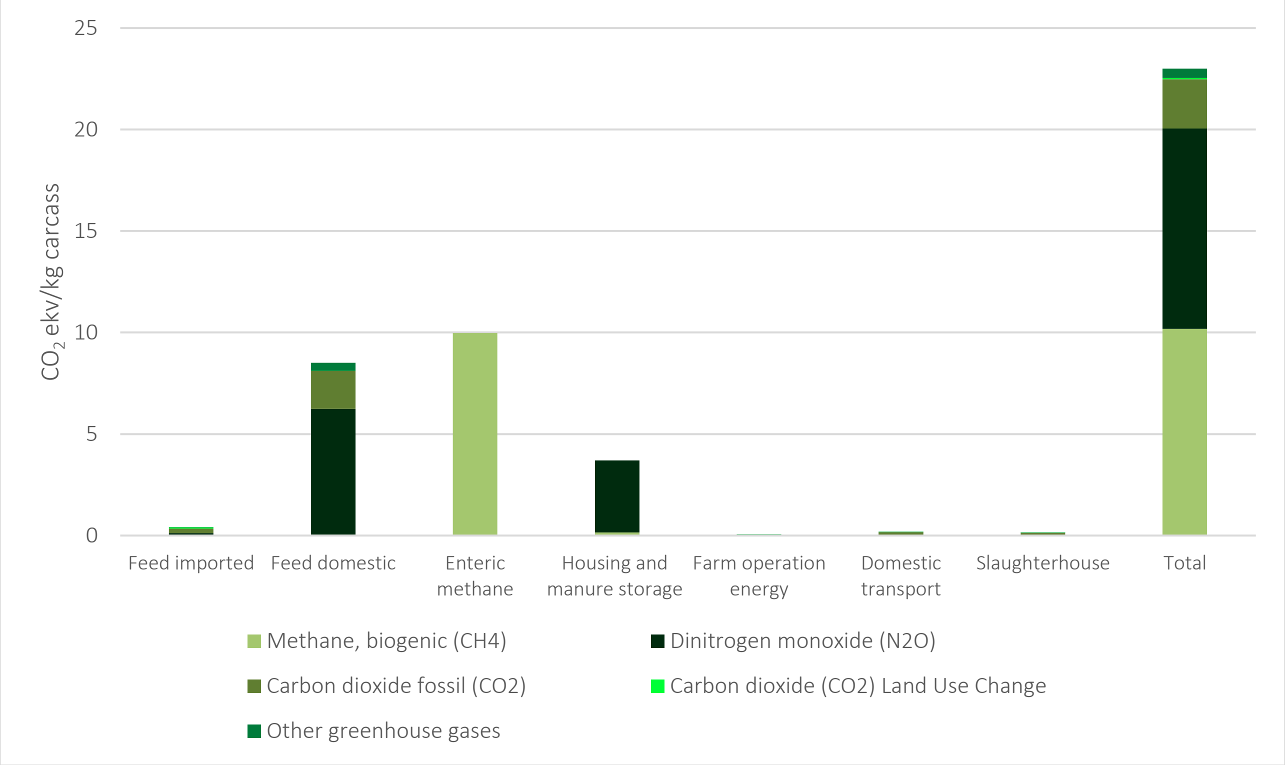

Figure 3.15. Most of the emissions occur on the farm. Enteric methane is the largest single emission and accounts for 44% of total GHG emissions. Methane from manure storage is about 1% of total GHG emissions. This share of methane from manure storage is low due to a long grazing period and because the 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

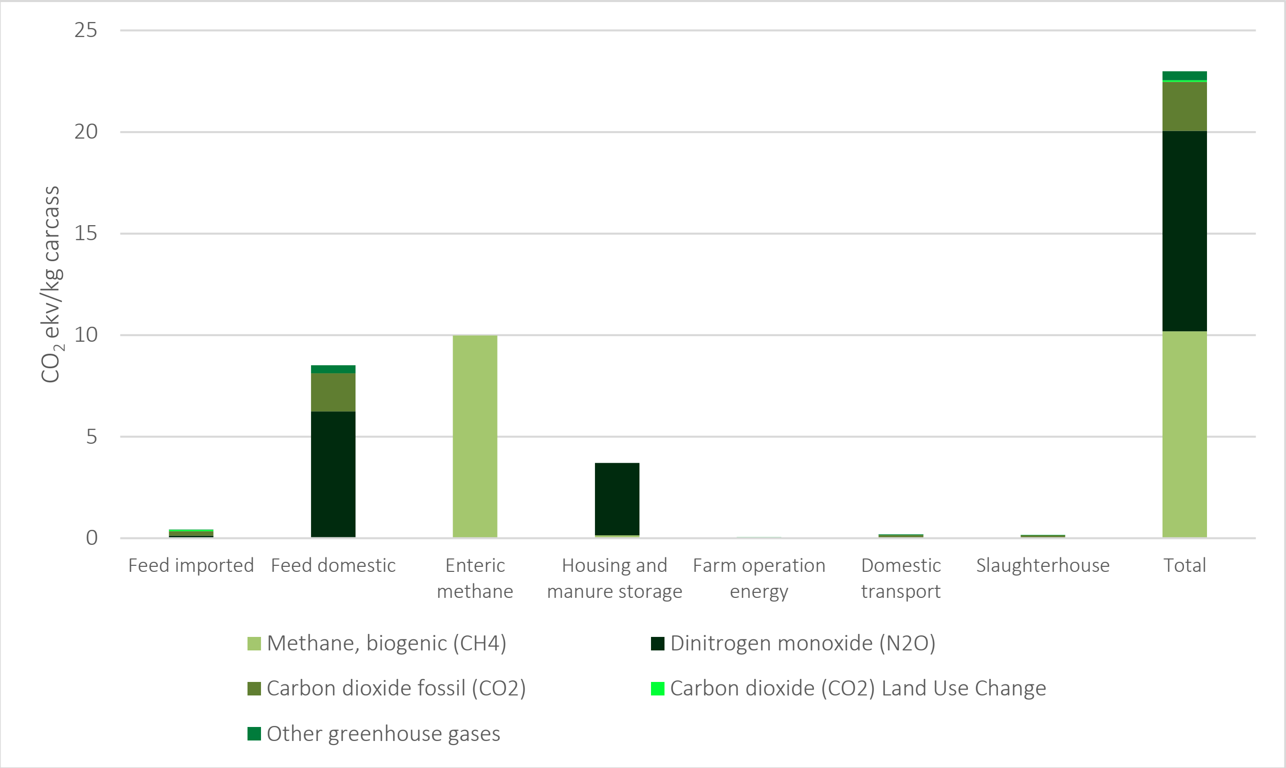

Figure 3.15.

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

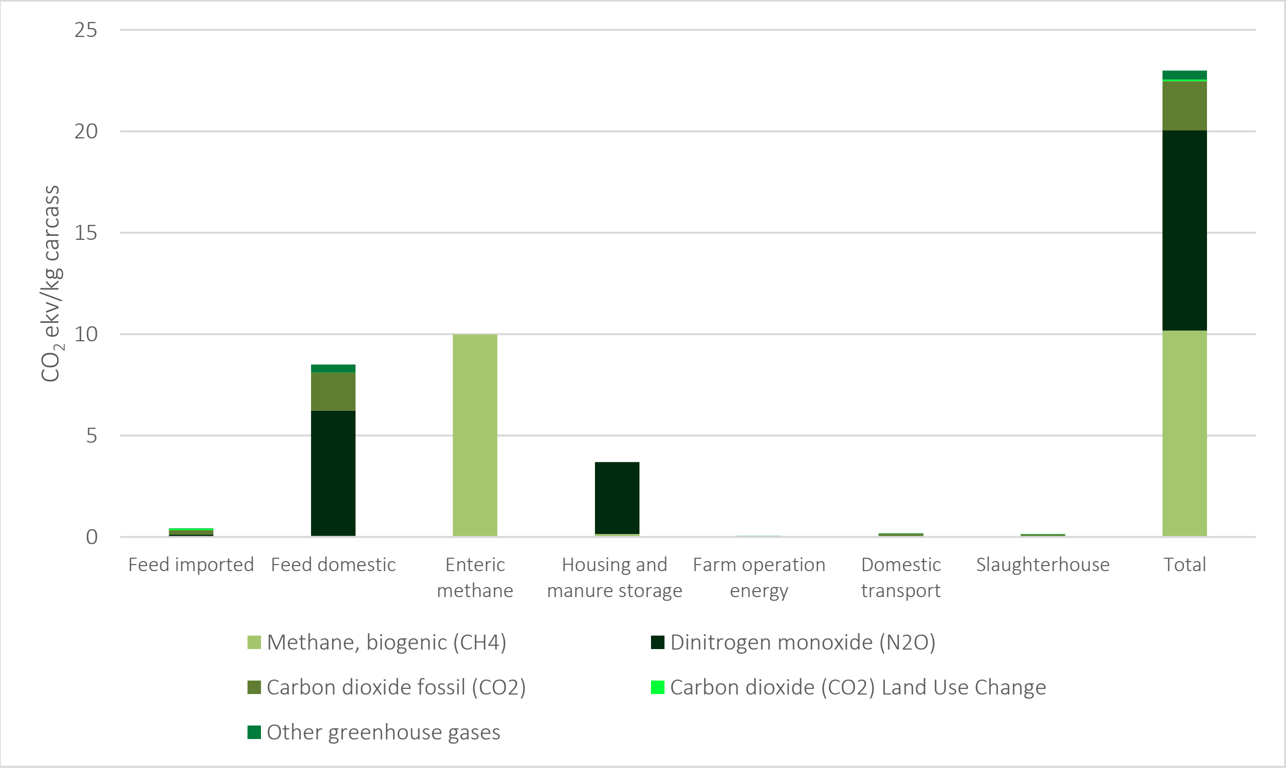

Figure 3.15 shown under domestic feed, which consists of forage and feed concentrate. Other emissions from domestic feed production are CO_2 (8%) which results from the use of fuel for tillage and harvesting. Emissions from the slaughterhouse are from energy use and is less than 1% of total GHG emissions. Other greenhouse gases are from processes related to input factors.

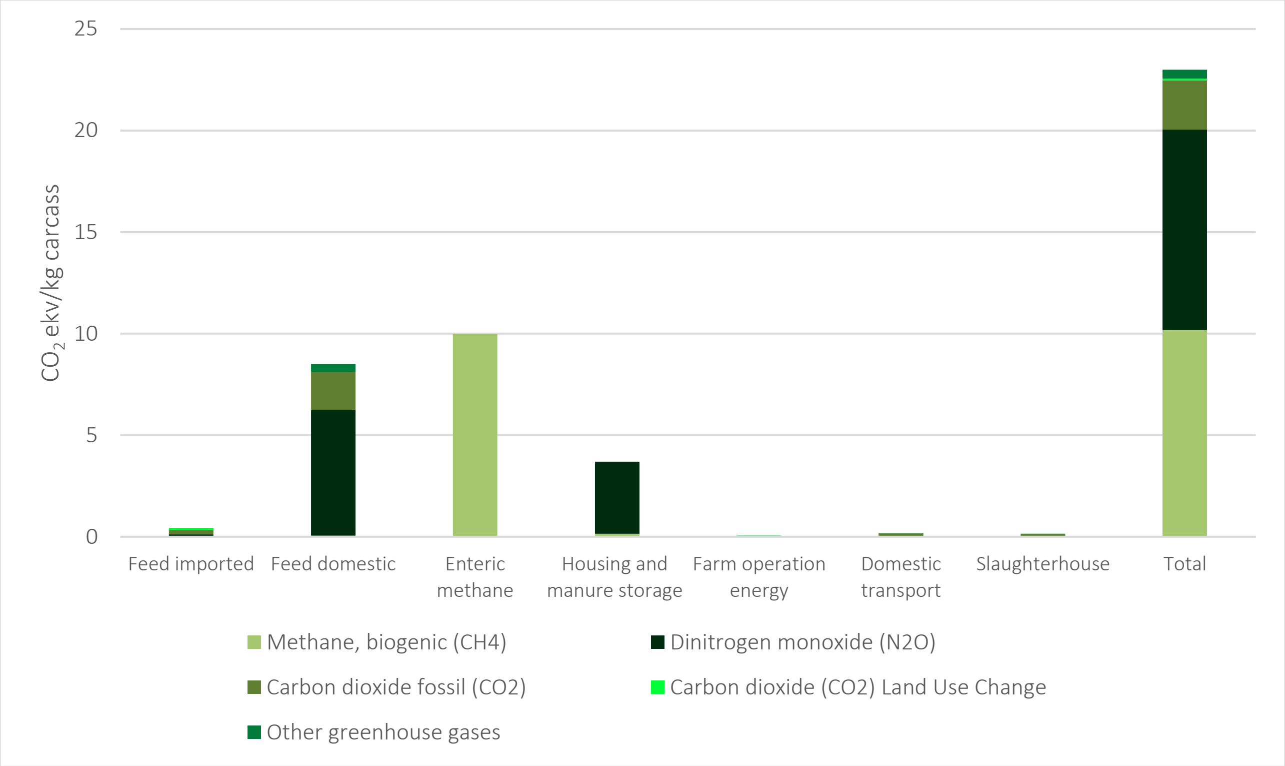

Figure 3.15 Climate change (CO_2 eqv.) per kg carcass through the life cycle (cradle to slaughterhouse gate) of sheep and lamb.

3.3.2 Land occupation

Land occupation for production of feed is shown in Figure 3.16, 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.

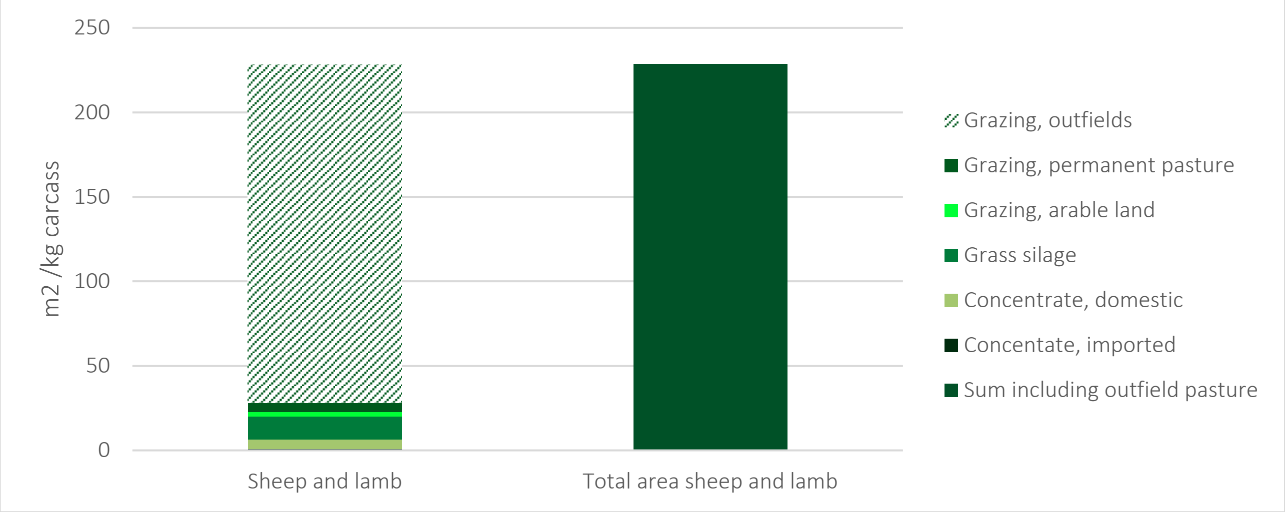

Figure 3.16 Land occupation (m^2) distributed by land category per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate).

3.3.3 Biodiversity

Loss of biodiversity linked to land for feed production is shown in Figure 3.17, 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.

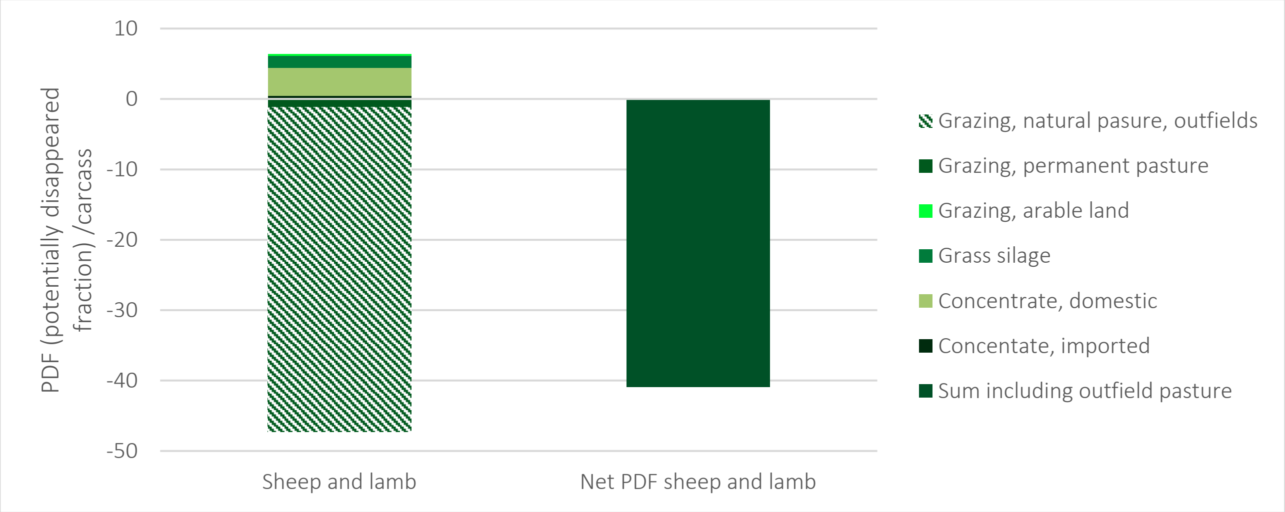

Figure 3.17 Biodiversity as potential disappeared fraction (PDF; Knudsen et al., 2017) per kg carcass of sheep and lamb

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 3.18 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.

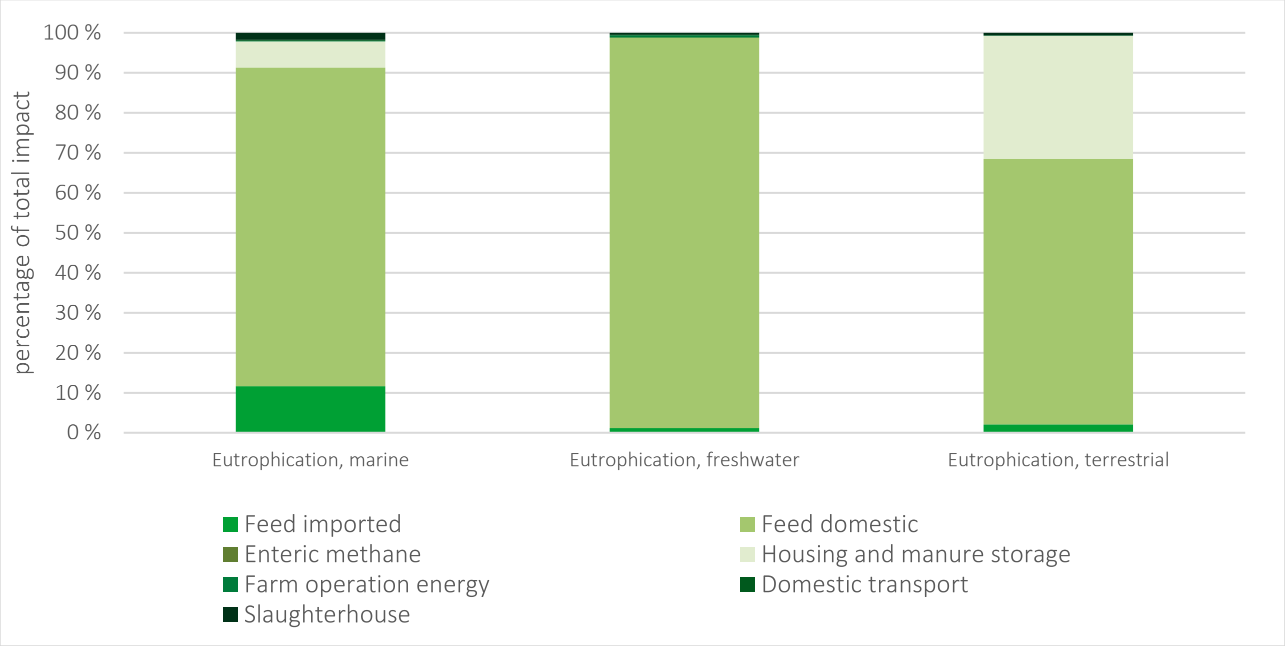

Figure 3.18 Marine eutrophication, freshwater eutrophication and terrestrial eutrophication per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category

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 3.19 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.

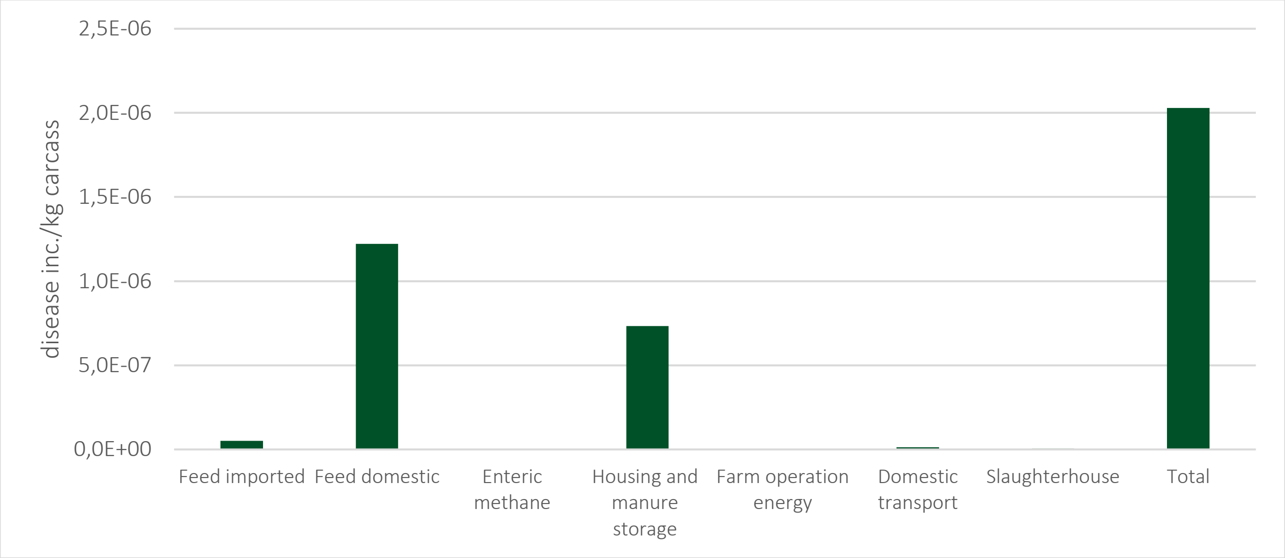

Figure 3.19 Particulate matter (disease inc.) per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate).

3.3.6 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 3.20, 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%).

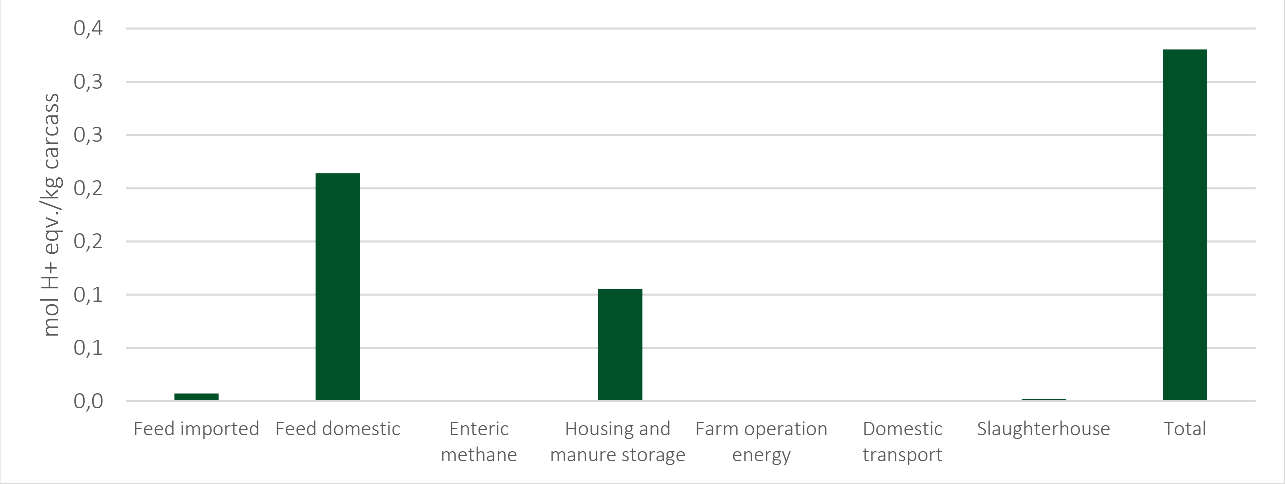

Figure 3.20 Acidification (mol H^+ eqv.) per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate).

3.3.7 Water scarcity

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 3.21 shows that the domestic feed has the largest water scarcity (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.

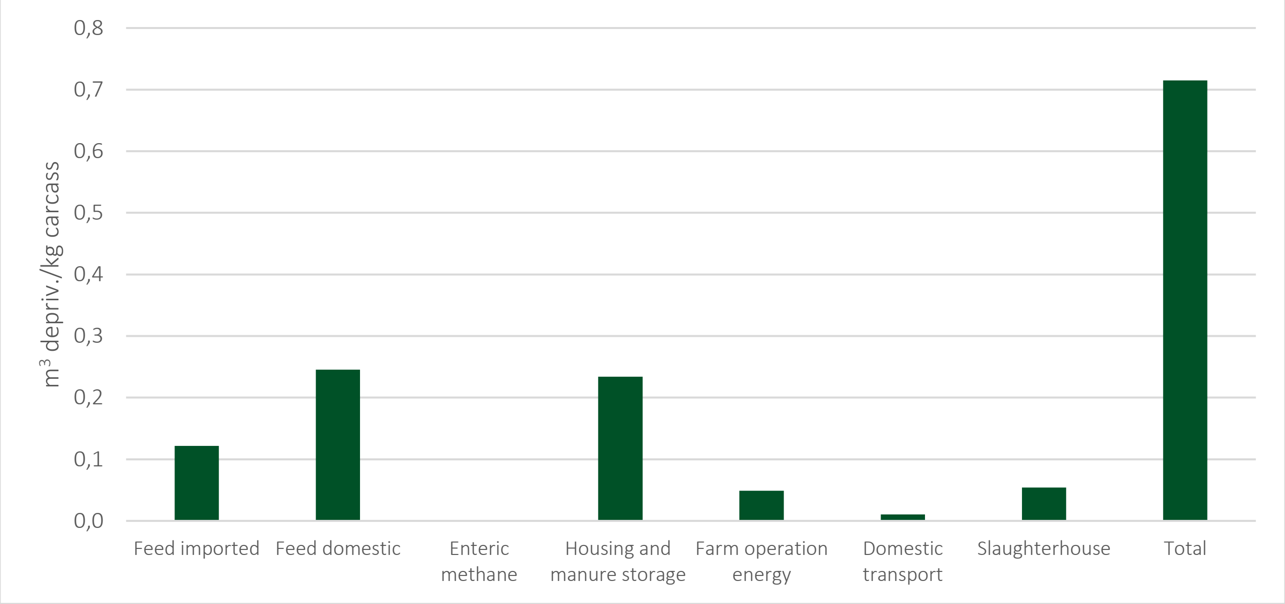

Figure 3.21 Water scarcity (m^3 depriv.) per kg carcass of sheep and lamb through the life cycle (cradle to slaughterhouse gate).

3.4 Pork

The total environmental impacts of pig are provided in Table 3.4. Detailed results for each environmental impact throughout the life cycle are shown in the following figures.

However, for the biodiversity impact, only the total impact can be shown as the method used cannot distinguish between different crops and uses the same characterisation factors for arable land. Hence, the total value for biodiversity is shown in Table 3.4.

Conversion from carcass to consumer product and meat and protein is based on factors in Table 2.1 and Table 2.2.

Table 3.4 Total environmental impacts of pig at per kg of carcass, consumer product, edible meat and protein.

Impact category and unit	**Impacts per kg of carcass**	**Impact per kg consumer product**	**Impacts per kg of edible meat**	**Impacts per kg of protein**
GHG, total (kg CO_2 eqv)	3.4	4.8	4.9	24
GHG, methane biogenic (kg CO_2 eqv)	*0.7*	*1.0*	*1.0*	*4.7*
GHG, nitrous oxide (kg CO_2 eqv)	*0.6*	*0.9*	*0.9*	*4.2*
GHG, carbon dioxide, fossil (kg CO_2 eqv)	*1.6*	*2.3*	*2.3*	*10.9*
GHG, carbon dioxide, Land Use Change (kg CO_2 eqv)	*0.04*	*0.1*	*0.1*	*0.3*
GHG, other greenhouse gases (kg CO_2 eqv)	*0.5*	*0.7*	*0.7*	*3.3*
Land occupation (m^2)	6.5	9.4	9.6	46
Biodiversity (PDF)	4.3	6.2	6.3	30
Eutrophication, marine (kg N eqv)	0.010	0.015	0.015	0.073
Eutrophication, freshwater (kg P eqv)	0.001	0.0013	0.0013	0.006
Eutrophication, terrestrial (mol N eqv)	0.22	0.32	0.33	1.55
Particulate matter (disease inc.)	4.3E-07	5.8E-07	6.0E-07	2.8E-06
Acidification (mol H+ eqv)	0.05	0.08	0.08	0.38
Water scarcity, deprivation-weighted (m^3 depriv.)	0.5	0.7	0.8	3.6

3.4.1 Climate change

The GHG emissions from pig is shown in Figure 3.22. 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).

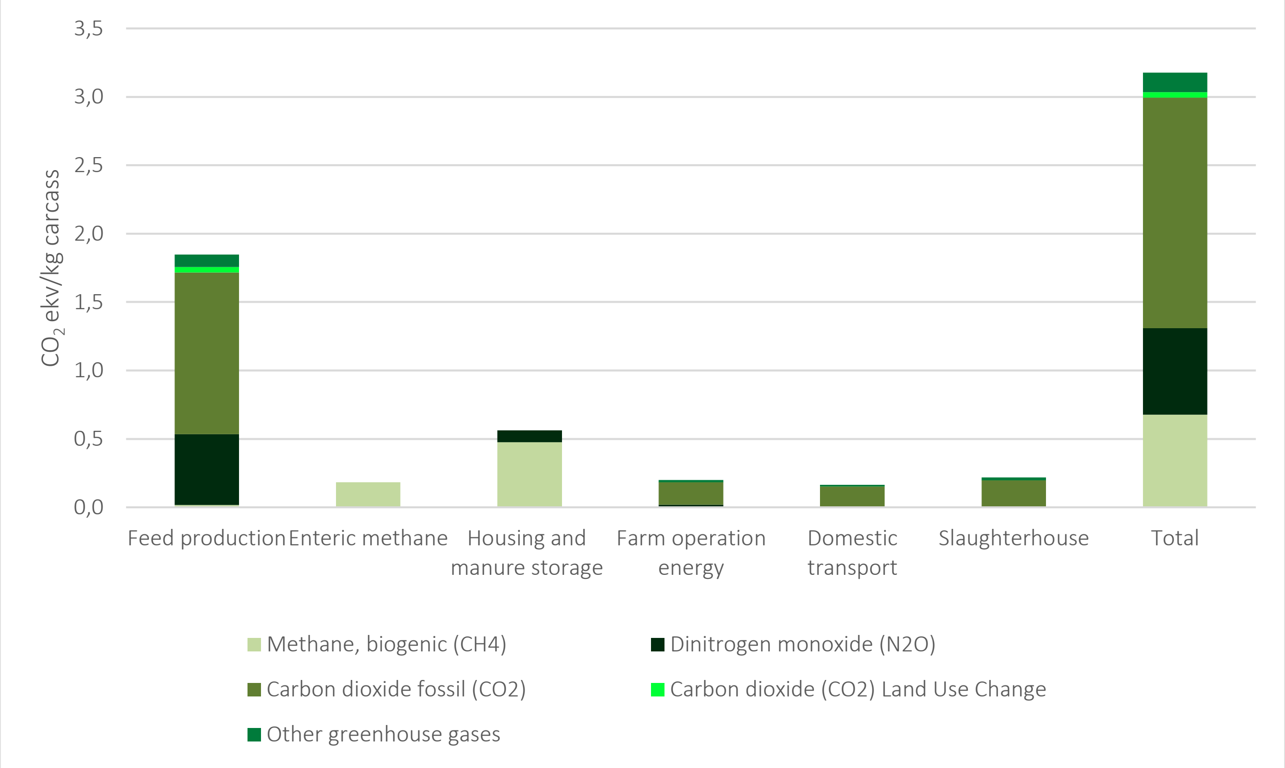

Figure 3.22 Climate change (CO_2 eqv.) per kg carcass of pig through the life cycle (cradle to slaughterhouse gate)

3.4.2 Land occupation

Land occupation for production of feed and energy production, industry and roads are shown in Figure 3.23. 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%.

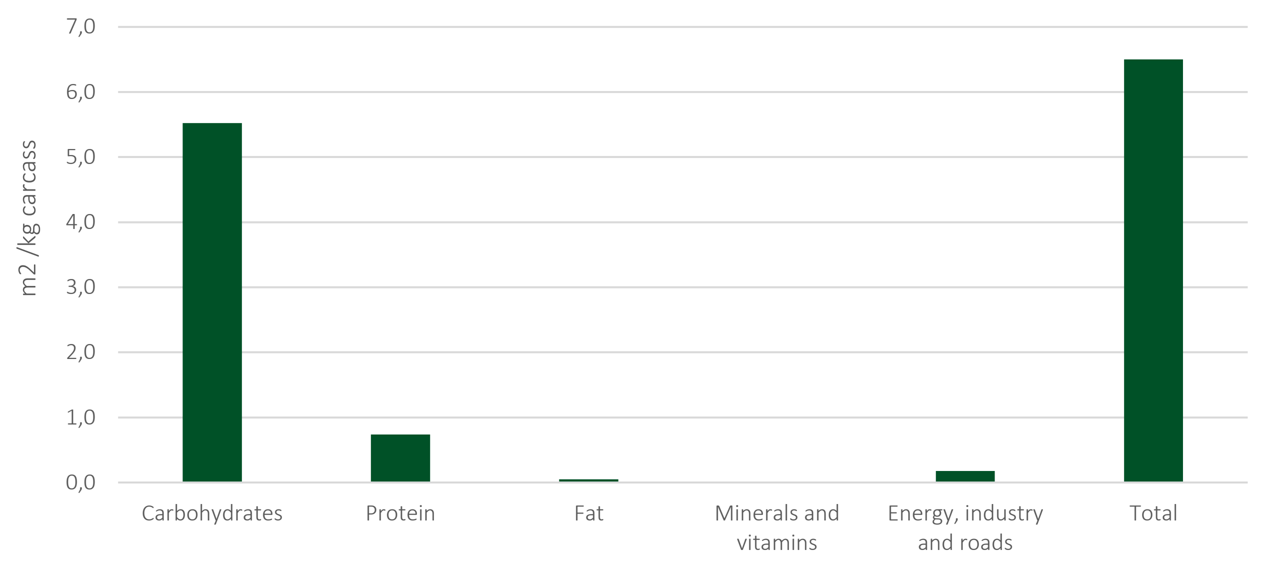

Figure 3.23 Land occupation (m^2) distributed by land category per kg carcass of pig through the life cycle (cradle to the slaughterhouse gate).

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 3.24 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.

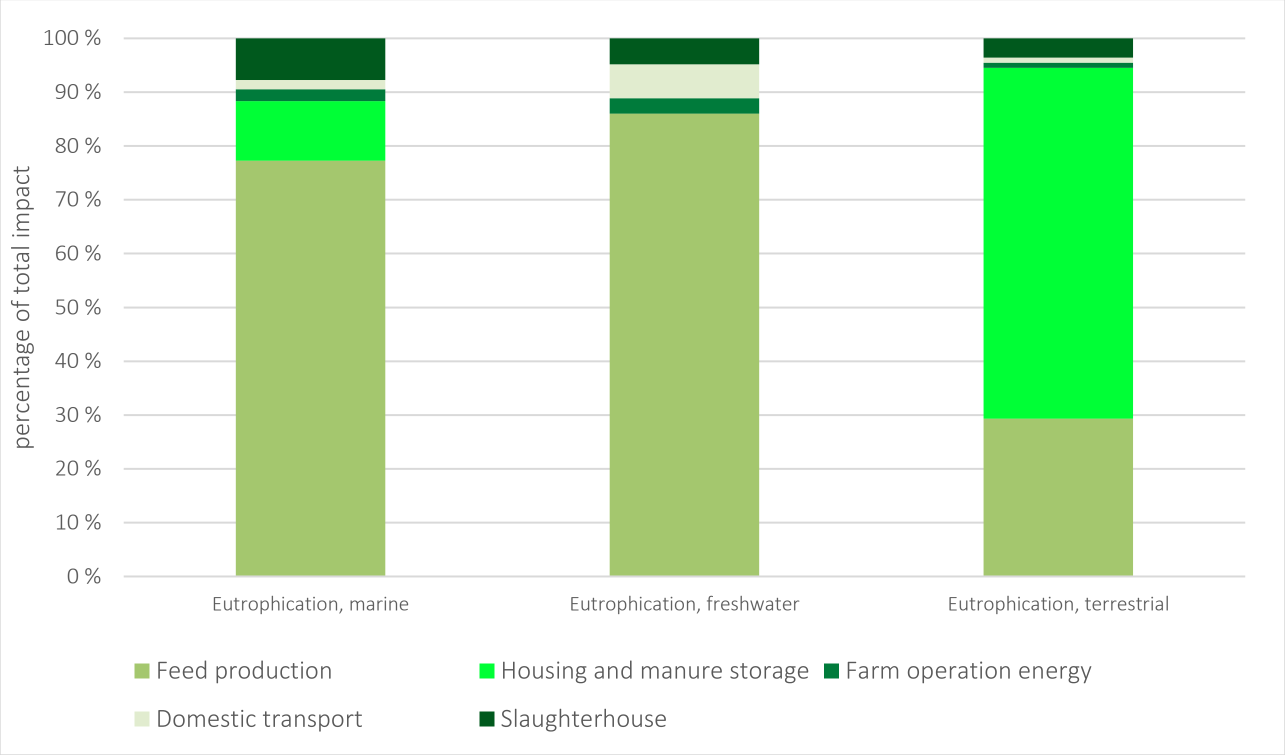

Figure 3.24 Marine eutrophication, freshwater eutrophication, and terrestrial eutrophication per kg carcass of pig through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category.

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 3.25 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.

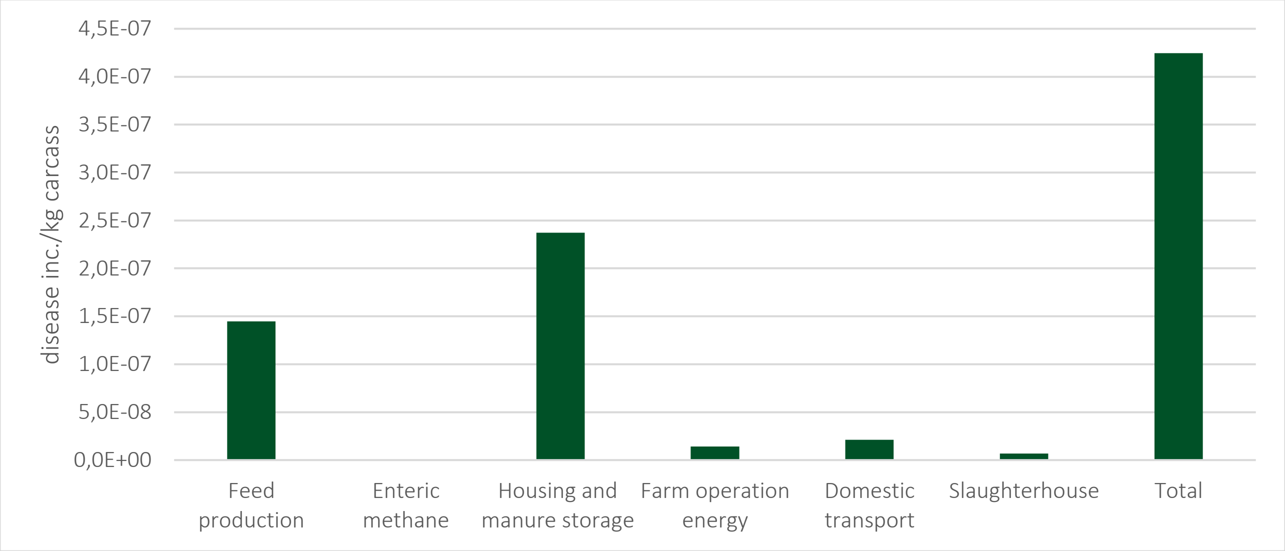

Figure 3.25 Particulate matter (disease inc.) per kg carcass of pig through the life cycle (cradle to slaughterhouse gate).

3.4.5 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 3.26, 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%).

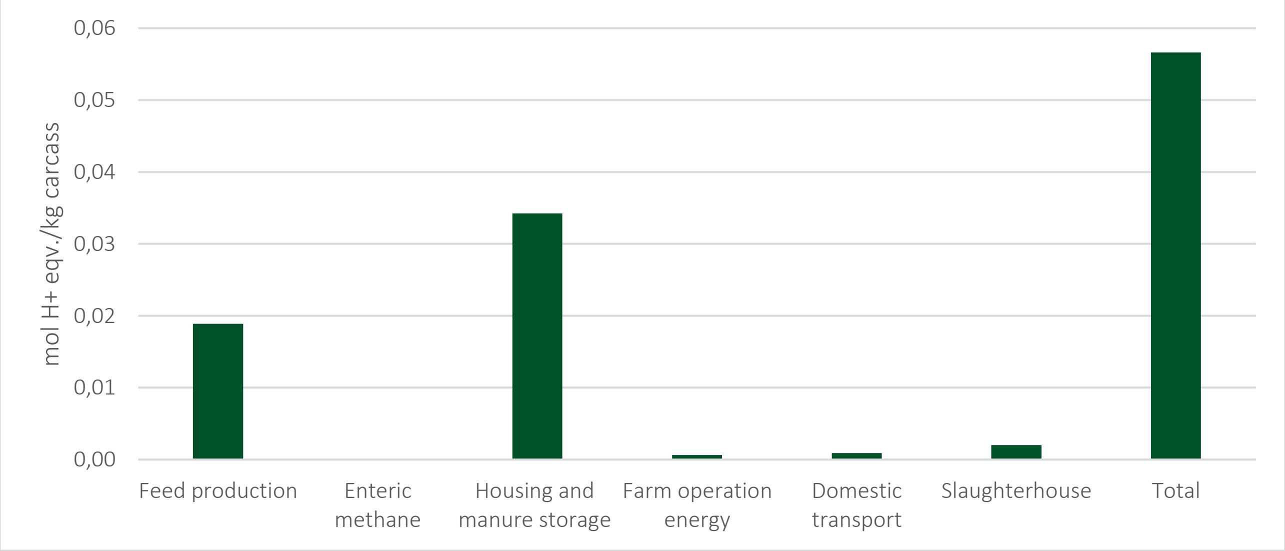

Figure 3.26 Acidification (mol H^+ eqv.) per kg carcass of pig through the life cycle (cradle to slaughterhouse gate).

3.4.6 Water scarcity

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 3.27 shows that feed production has the largest water scarcity (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.

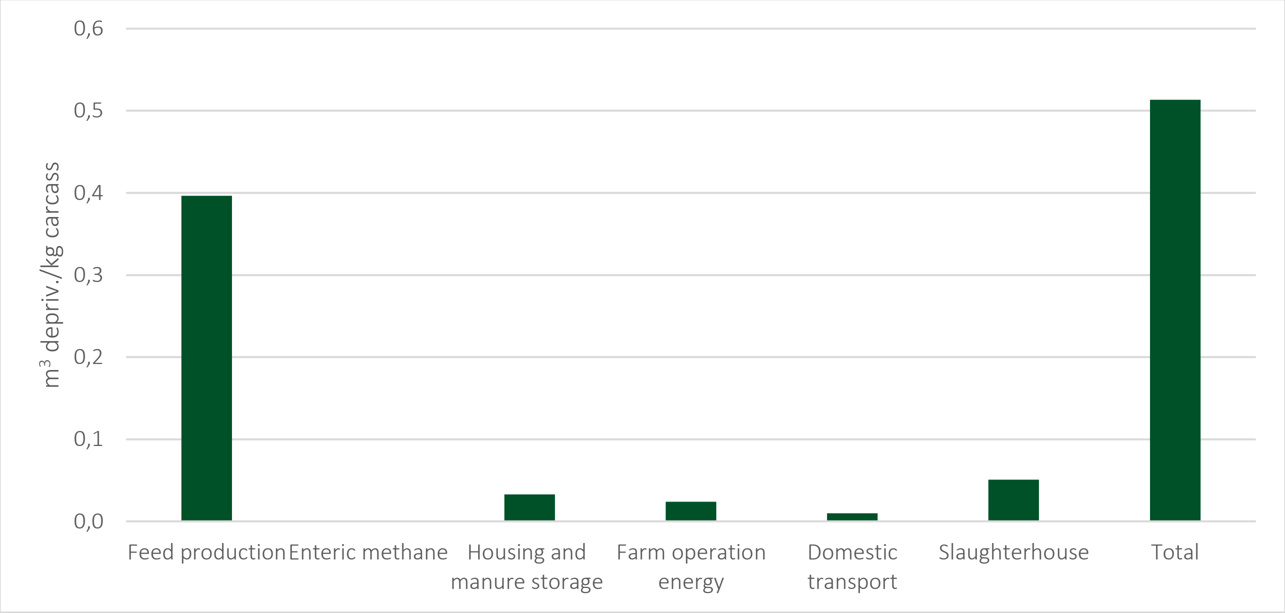

Figure 3.27 Water scarcity (m^3 depriv.) per kg carcass of pig through the life cycle (cradle to slaughterhouse gate).

3.5 Chicken

The total environmental impacts of chicken are provided in Table 3.5. Detailed results for each environmental impact throughout the life cycle are shown in the following figures.

However, this does not apply to the biodiversity impact as the method used cannot not distinguish between different crops and uses the same characterisation factors for arable land. Hence, the total value for biodiversity is shown in Table 3.5.

Conversion from carcass to consumer product and meat and protein is based on factors in Table 2.1 and Table 2.2.

Table 3.5 Total environmental impacts of chicken per kg of carcass, consumer product, edible meat and protein.

Impact category and unit	**Impacts per kg of carcass**	**Impact per kg consumer product**	**Impacts per kg of edible meat**	**Impacts per kg of protein**
GHG, total (kg CO_2 eqv)	2.3	3.5	-	19
GHG, methane biogenic (kg CO_2 eqv)	*0.1*	*0.2*	-	*0.9*
GHG, nitrous oxide (kg CO_2 eqv)	*0.4*	*0.7*	-	*3.6*
GHG, carbon dioxide, fossil (kg CO_2 eqv)	*1.5*	*2.4*	-	*13*
GHG, carbon dioxide, Land Use Change (kg CO_2 eqv)	*0.04*	*0.07*	-	*0.36*
GHG, other greenhouse gases (kg CO_2 eqv)	*0.13*	*0.20*	-	*1.0*
Land occupation (m^2)	4.4	6.9	-	36
Biodiversity (PDF)	2.9	4.6	-	24
Eutrophication, marine (kg N eqv)	0.01	0.02	-	0.10
Eutrophication, freshwater (kg P eqv)	0.0006	0.0010		0.0051
Eutrophication, terrestrial (mol N eqv)	0.12	0.19	-	0.98
Particulate matter (disease inc.)	2.0E-07	3.1E-07	-	1.6E-06
Acidification (mol H+ eqv)	0.03	0.04	-	0.23
Water scarcity, deprivation-weighted (m^3 depriv.)	2.1	3.2	-	17

3.5.1 Climate change

The GHG emissions from chicken is shown in Figure 3.28. 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).

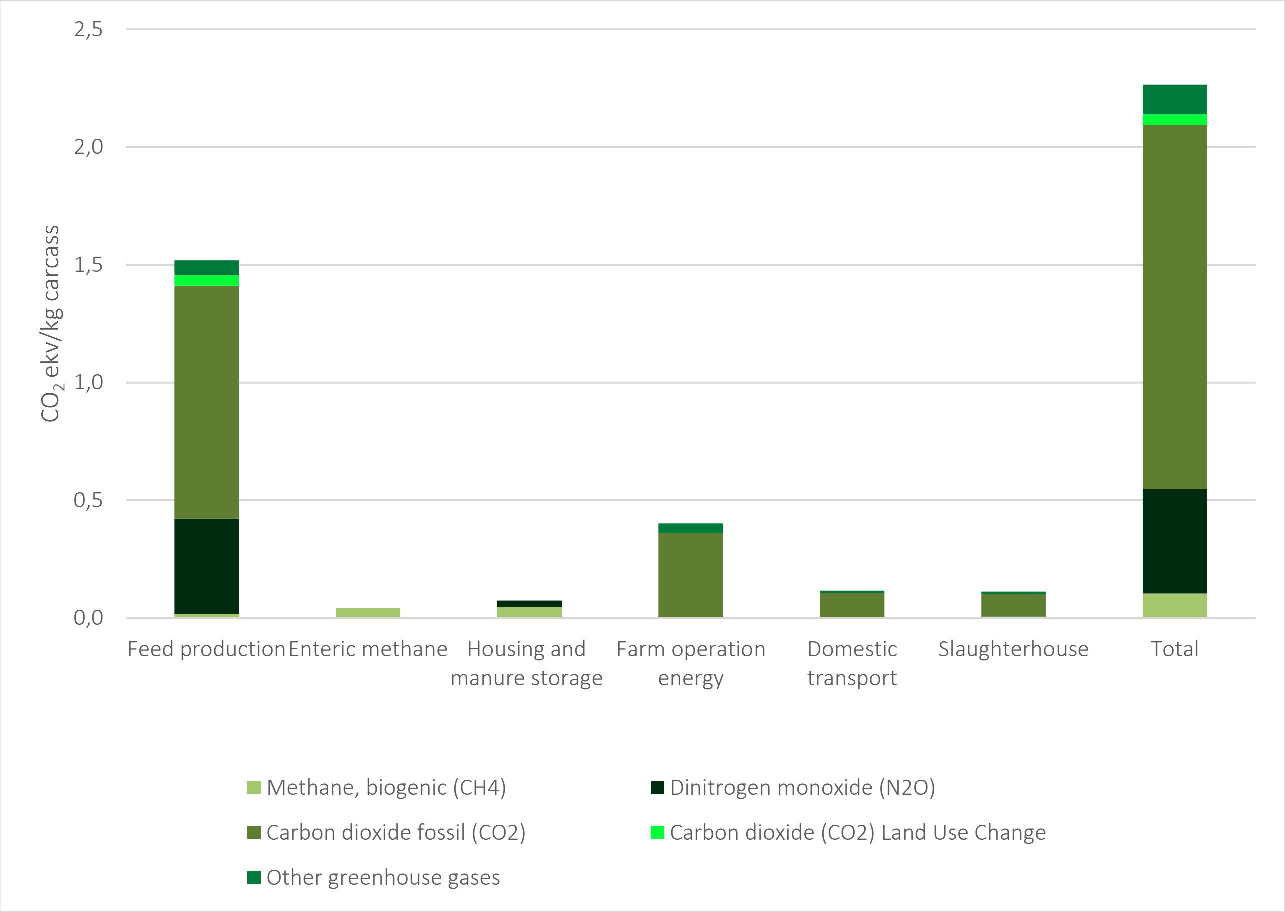

Figure 3.28 Climate change (CO_2 eqv.) per kg carcass of chicken through the life cycle (cradle to slaughterhouse gate).

3.5.2 Land occupation

Land occupation for production of feed and energy production, industry and roads are shown in Figure 3.29. 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%.

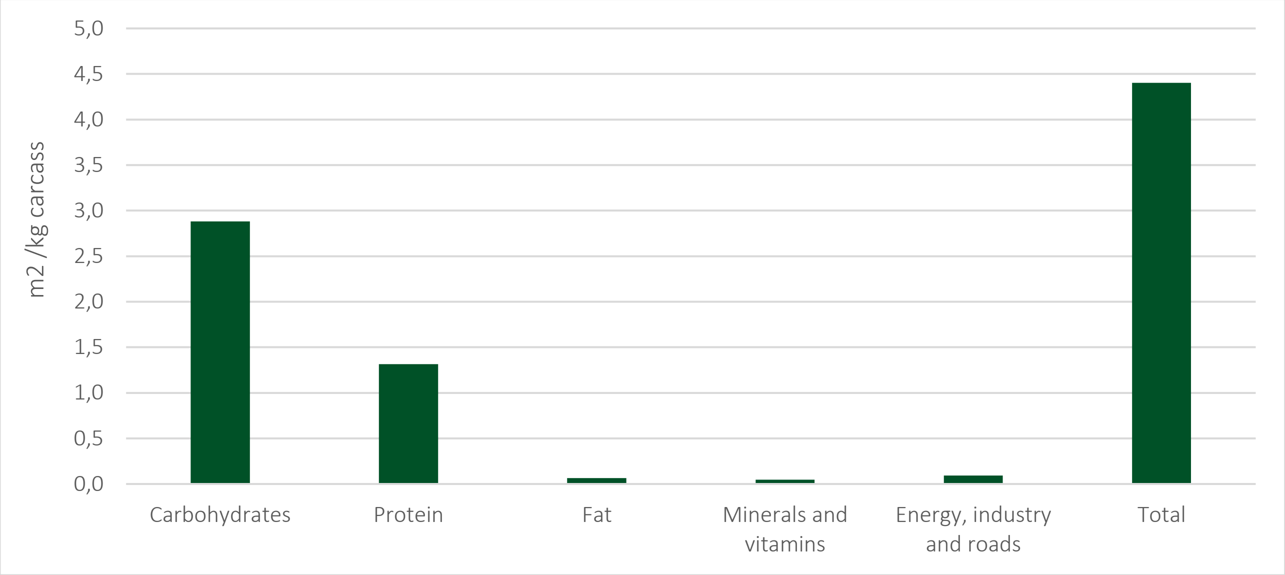

Figure 3.29 Land occupation (m²) distributed by land category per kg carcass of chicken through the life cycle (cradle to the slaughterhouse gate).

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 3.30 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.

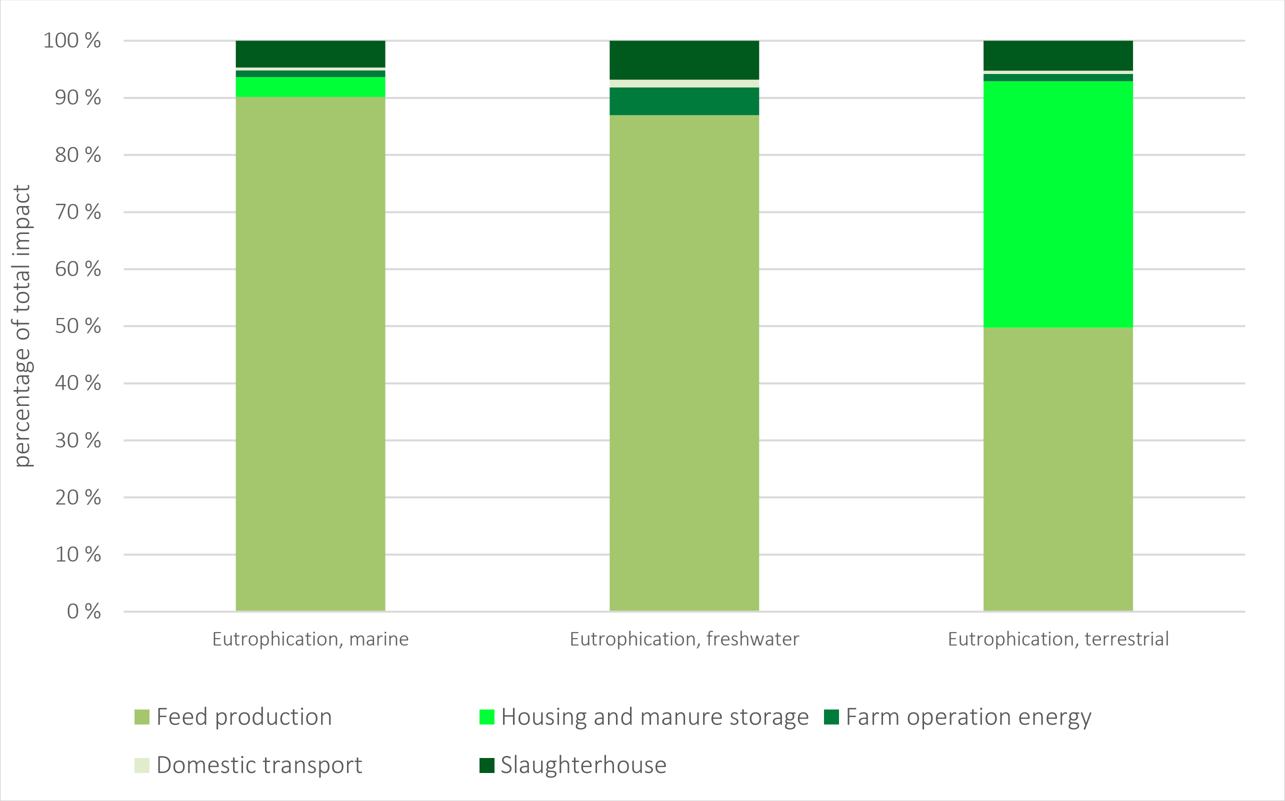

Figure 3.30 Marine eutrophication, freshwater eutrophication, and terrestrial eutrophication per kg carcass of chicken through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category

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 3.31 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.

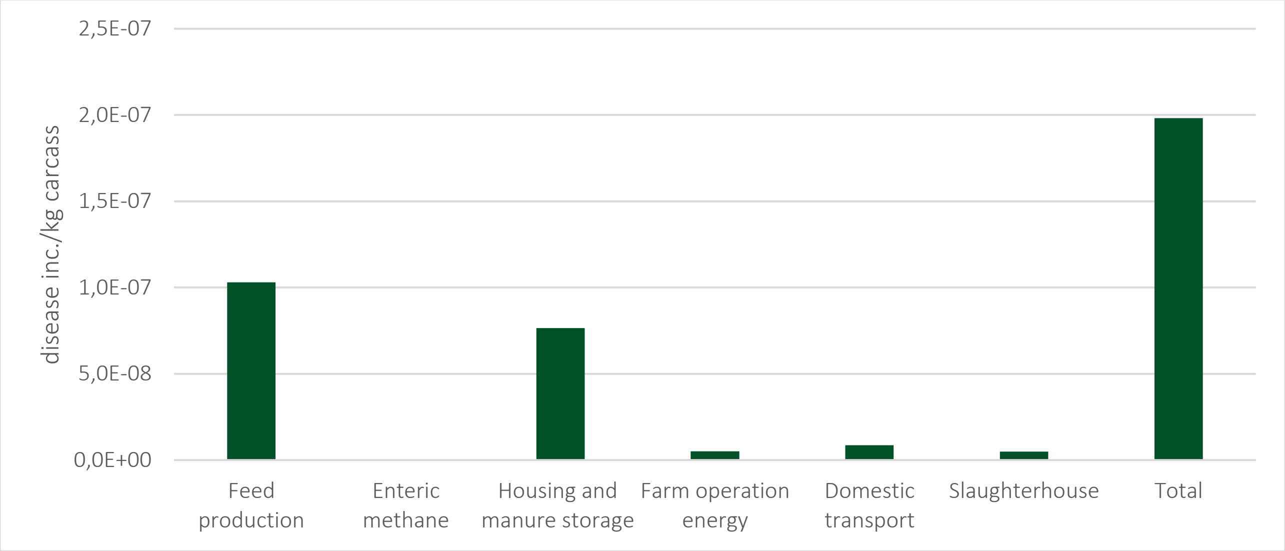

Figure 3.31 Particulate matter (disease inc.) per kg carcass of chicken through the life cycle (cradle to slaughterhouse gate).

3.5.5 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 3.32 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%).

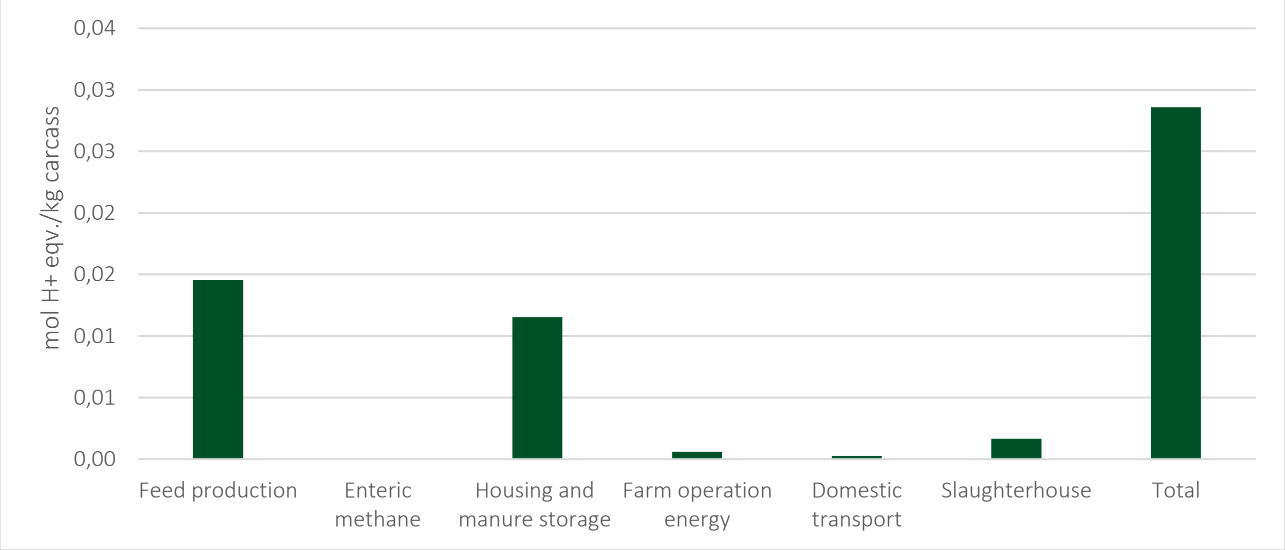

Figure 3.32 Acidification (mol H^+ eqv.) per kg carcass of chicken through the life cycle (cradle to the gate of the slaughterhouse).

3.5.6 Water scarcity

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 3.33 shows that feed production has the largest water scarcity (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.

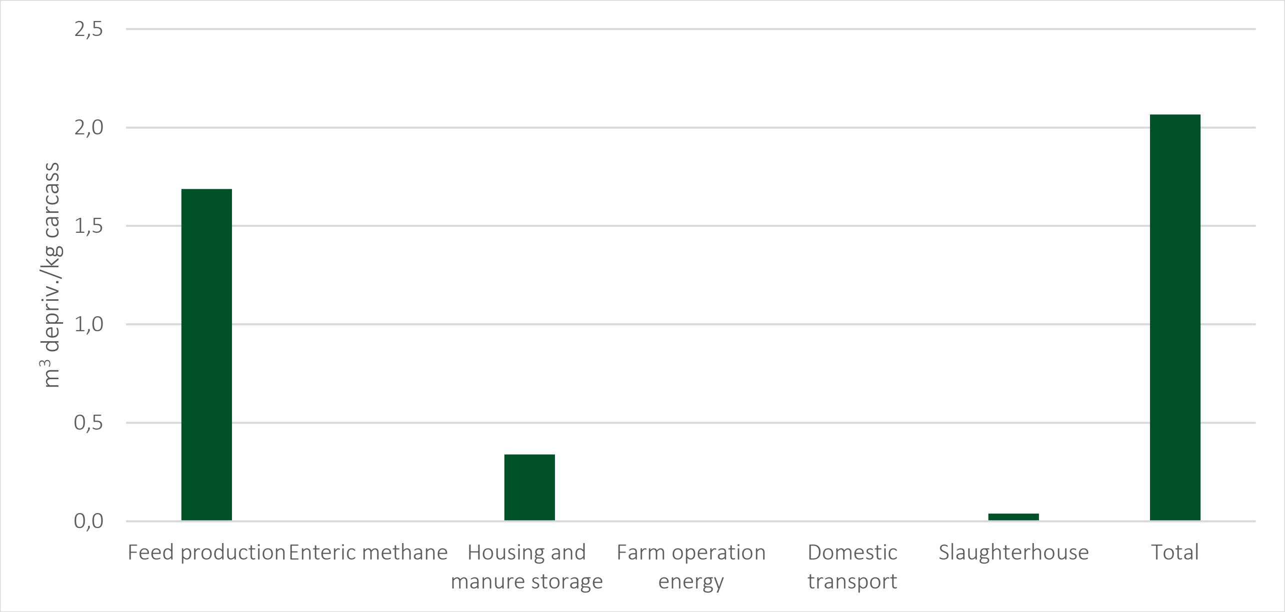

Figure 3.33 Water scarcity (m^3 depriv.) per kg carcass of chicken through the life cycle (cradle to slaughterhouse gate).

3.6 Turkey

The total environmental impacts of turkey are provided in Table 3.6. 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. Hence, the total value for biodiversity is shown in Table 3.6.

Conversion from carcass to consumer product and meat and protein is based on factors in Table 2.1 and Table 2.2.

Table 3.6 Total environmental impacts of turkey per kg of carcass, consumer product, edible meat and protein.

Impact category and unit	**Impacts per kg of carcass**	**Impact per kg consumer product**	**Impacts per kg of edible meat**	**Impacts per kg of protein**
GHG, total (kg CO_2 eqv)	2.3	3.5	-	18
GHG, methane biogenic (kg CO_2 eqv)	*0.2*	*0.3*	-	*1.6*
GHG, nitrous oxide (kg CO_2 eqv)	*0.7*	*1.0*	-	*5.3*
GHG, carbon dioxide, fossil (kg CO_2 eqv)	*1.3*	*1.9*	-	*10*
GHG, carbon dioxide, Land Use Change (kg CO_2 eqv)	*0.07*	*0.1*	-	*0.6*
GHG, other greenhouse gases (kg CO_2 eqv)	*0.1*	*0.2*	-	*0.8*
Land occupation (m^2)	6.3	9.5	-	50
Biodiversity (PDF)	4.1	6.2	-	32
Eutrophication, marine (kg N eqv)	0.01	0.02	-	0.10
Eutrophication, freshwater (kg P eqv)	0.0006	0.0010		0.005
Eutrophication, terrestrial (mol N eqv)	0.36	0.55	-	2.9
Particulate matter (disease inc.)	6.0E-07	9.0E-07	-	4.7E-06
Acidification (mol H+ eqv)	0.08	0.12	-	0.65
Water scarcity, deprivation-weighted (m^3 depriv.)	1.8	2.7	-	14

3.6.1 Climate change

The GHG emissions from turkey is shown in Figure 3.34. 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).

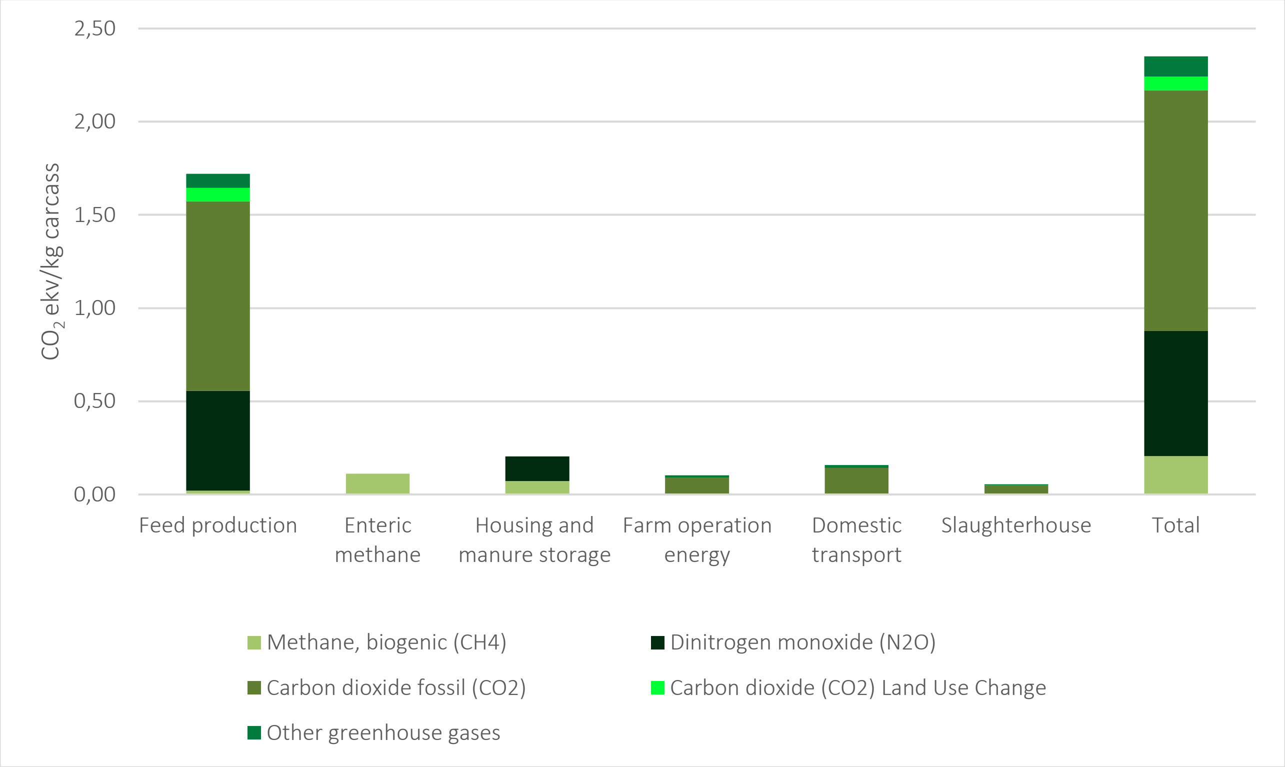

Figure 3.34 Climate change (CO_2 eqv.) per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate).

3.6.2 Land occupation

Land occupation for production of feed and energy production, industry and roads are shown in Figure 3.35. 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%.

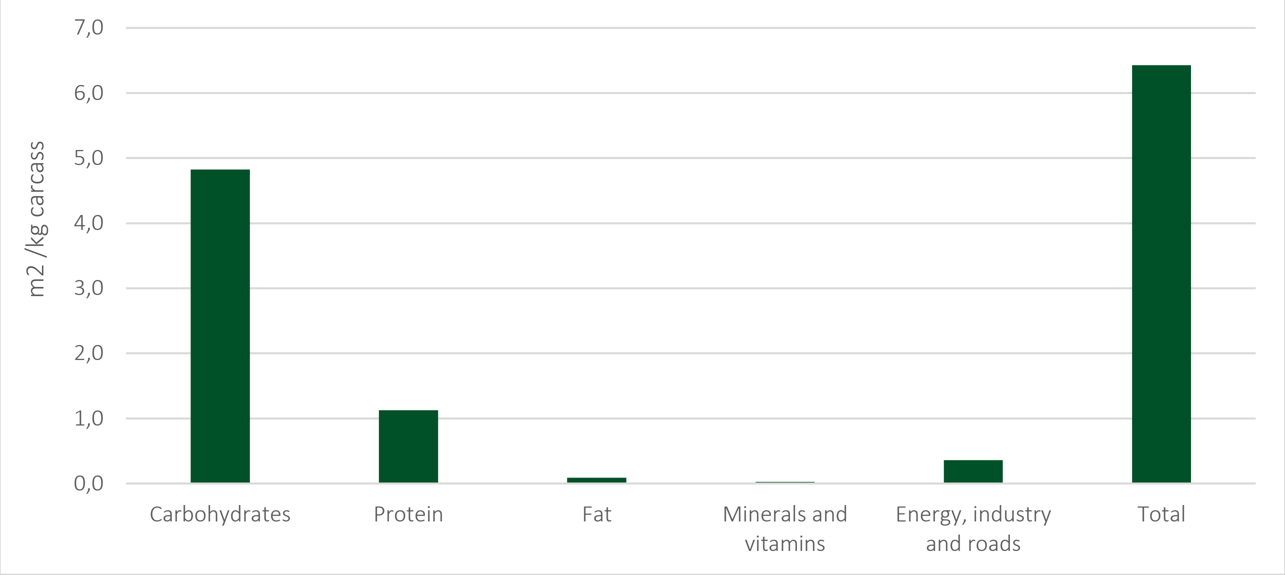

Figure 3.35 Land occupation (m^2) distributed by land category per kg carcass of turkey through the life cycle (cradle to the slaughterhouse gate).

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 3.36 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.

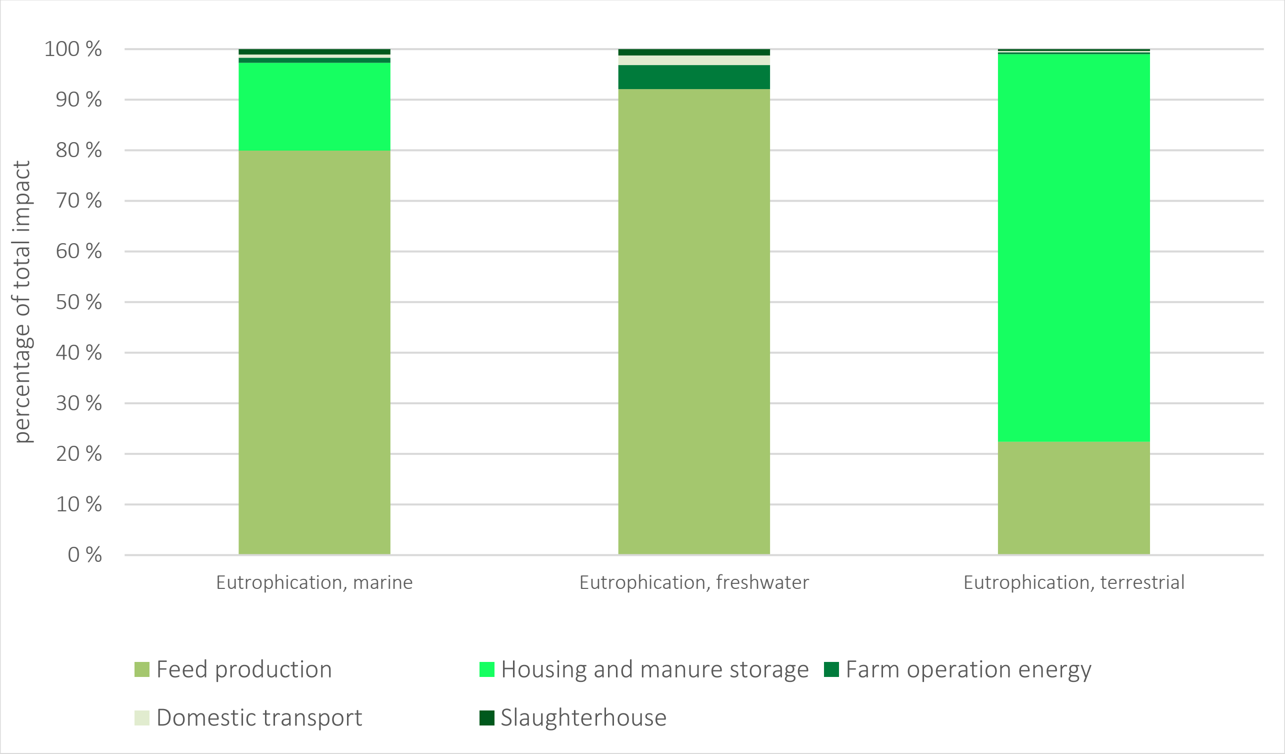

Figure 3.36 Marine eutrophication, freshwater eutrophication, and terrestrial eutrophication per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate) as percentage of total impact for each category.

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 3.37 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.

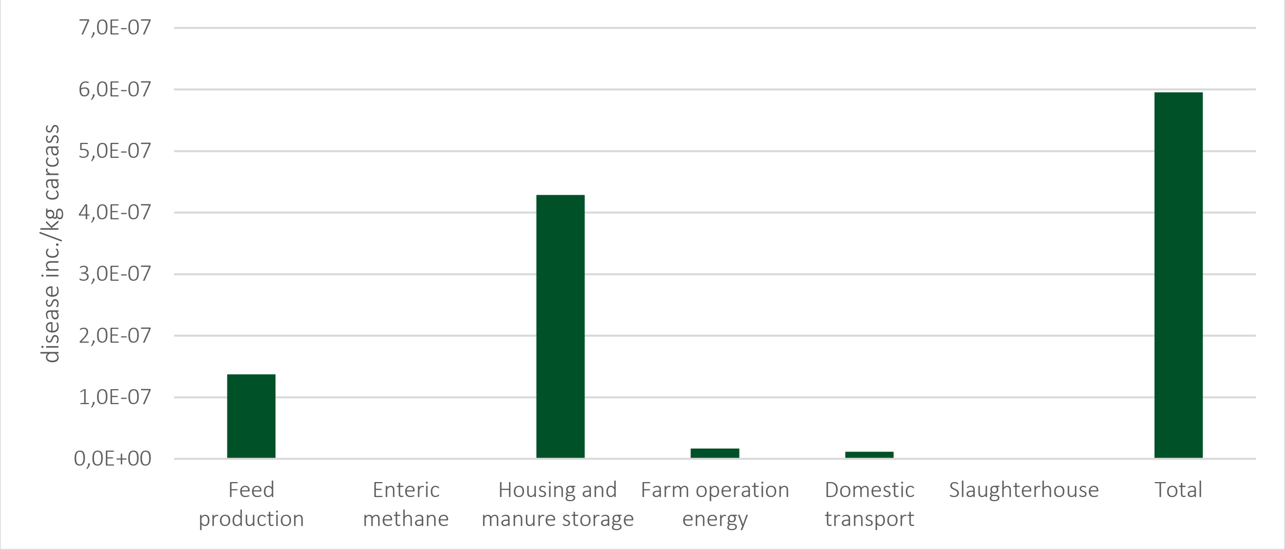

Figure 3.37 Particulate matter (disease inc.) per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate).

3.6.5 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 3.38, 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%).

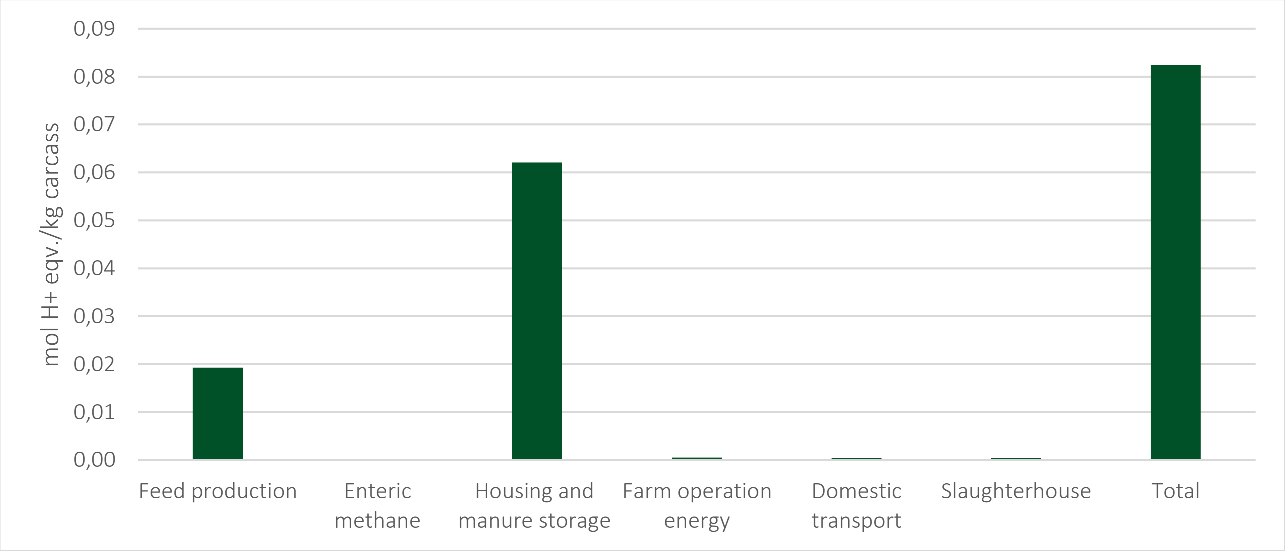

Figure 3.38 Acidification (mol H^+ eqv.) per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate).

3.6.6 Water scarcity

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 3.39 shows that feed production has the largest water scarcity (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.

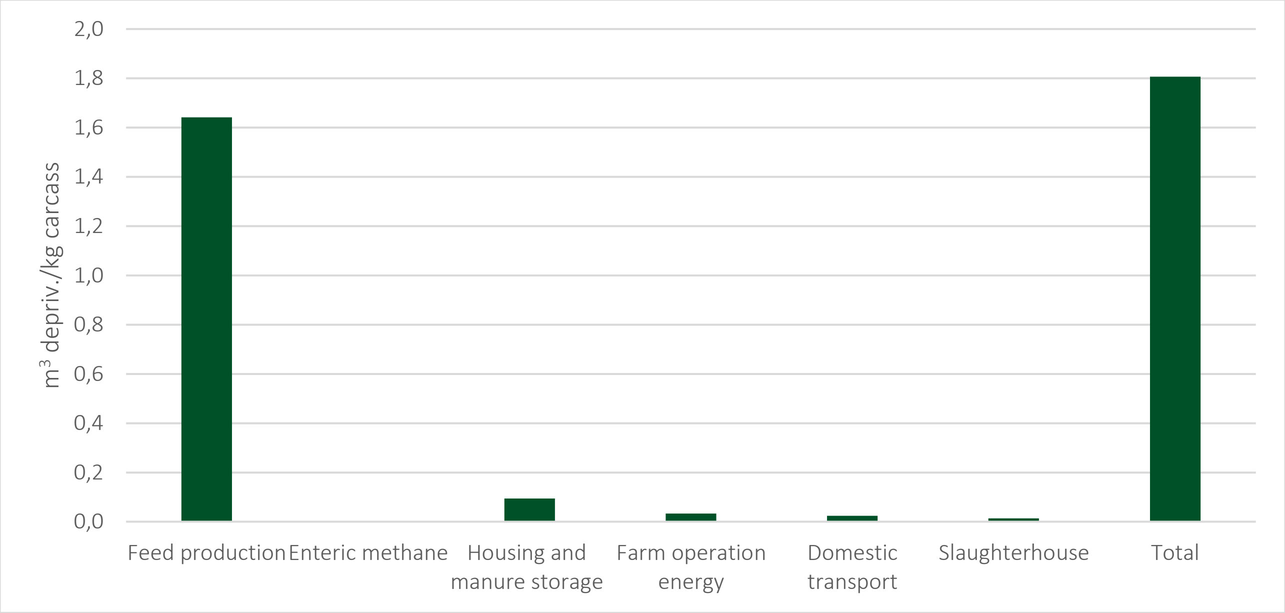

Figure 3.39 Water scarcity (m^3 depriv.) per kg carcass of turkey through the life cycle (cradle to slaughterhouse gate).

3.7 Egg

The total environmental impacts of eggs are provided in Table 3.7. Detailed results for each environmental impact throughout the life cycle are shown in the following figures.

However, for the biodiversity impact, the method used in this study cannot distinguish between different crops and uses the same characterisation factors for arable land. Hence, the total value for biodiversity is shown in Table 3.7.

Conversion from egg to protein is based on factors in Table 2.2.

Table 3.7 Total environmental impacts per kg egg per kg of egg and protein

Impact category and unit	Impacts per kg of egg	Impacts per kg of protein at egg packing and processing plant
GHG, total (kg CO_2 eqv)	1.5	12
GHG, methane biogenic (kg CO_2 eqv)	*0.1*	*0.8*
GHG, nitrous oxide (kg CO_2 eqv)	*0.4*	*3.0*
GHG, carbon dioxide, fossil (kg CO_2 eqv)	*0.9*	*7.2*
GHG, carbon dioxide, Land Use Change (kg CO_2 eqv)	*0.05*	*0.4*
GHG, other greenhouse gases (kg CO_2 eqv)	*0.08*	*0.6*
Land occupation, excl. outfields (m^2)	3.6	28
Biodiversity (PDF)	2.4	19
Eutrophication, marine (kg N eqv)	0.01	0.07
Eutrophication, freshwater (kg P eqv)	0.0004	0.0032
Eutrophication, terrestrial (mol N eqv)	0.12	0.91
Particulate matter (disease inc.)	2.0E-07	1.6E-06
Acidification (mol H+ eqv)	0.03	0.21
Water use, deprivation-weighted (m^3 depriv.)	1.4	11

3.7.1 Climate change

The GHG emissions from egg is shown in Figure 3.40. 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).

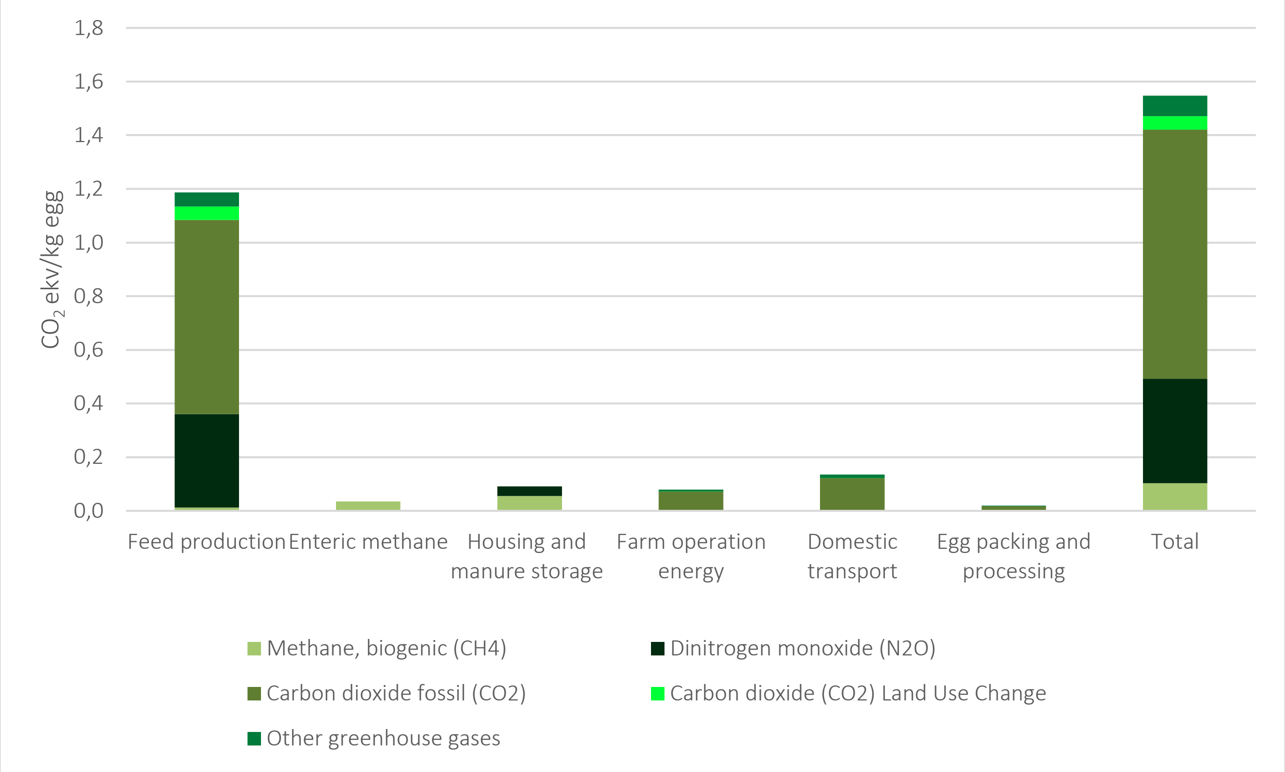

Figure 3.40 Climate change (CO_2 eqv.) per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant)

3.7.2 Land occupation

Land occupation for production of feed and energy production, industry and roads are shown in Figure 3.41. 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%.

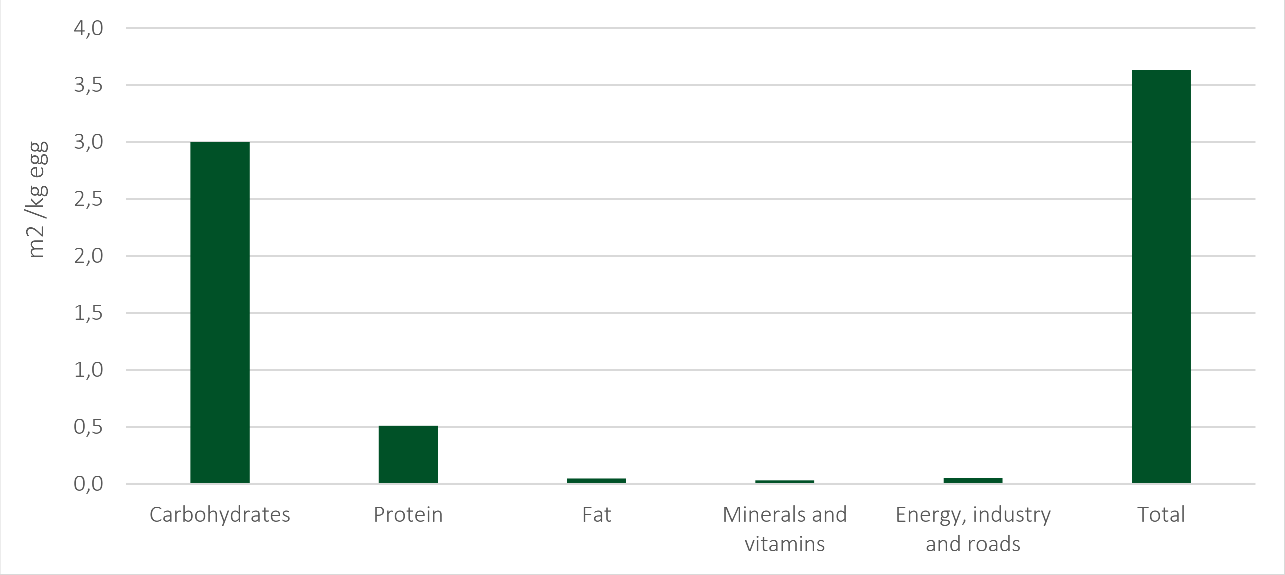

Figure 3.41 Land occupation (m^2) distributed by land category per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant).

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 3.42 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%.

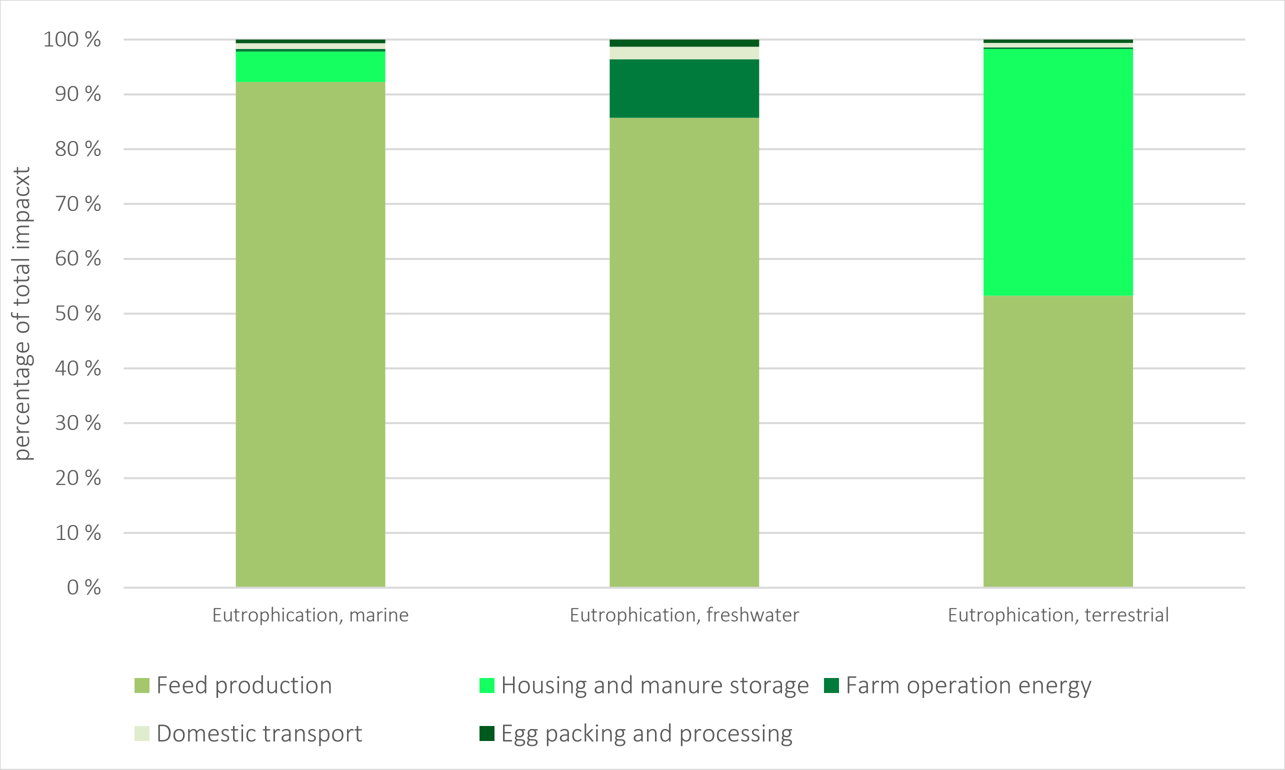

Figure 3.42 Marine eutrophication, freshwater eutrophication, and terrestrial eutrophication per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant) as percentage of total impact for each category.

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 3.43 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.

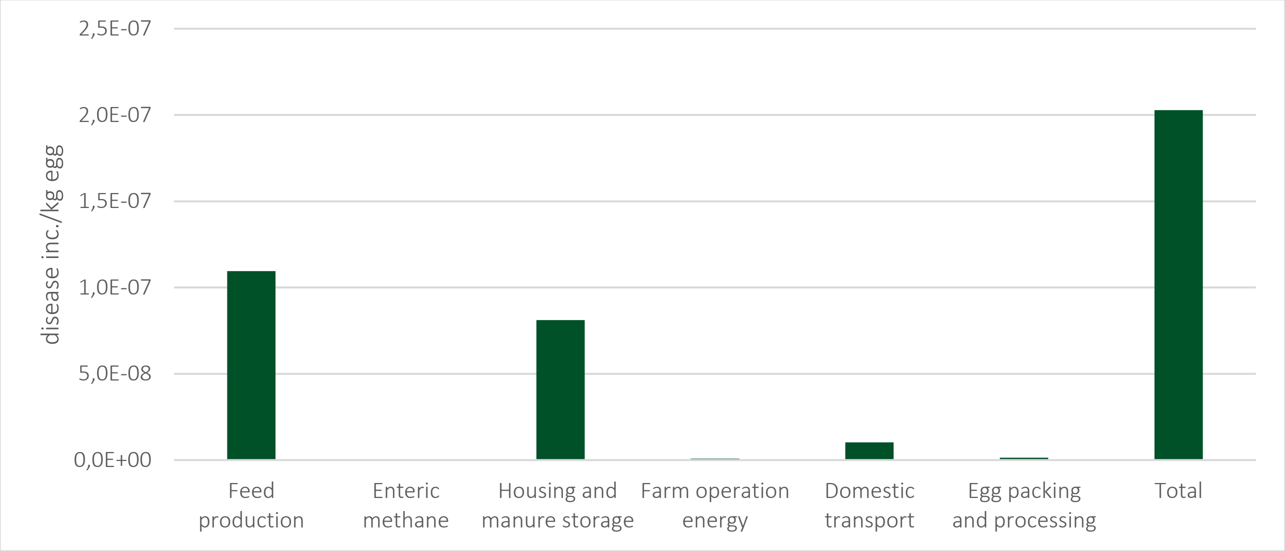

Figure 3.43 Particulate matter (disease inc.) per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant).

3.7.5 Acidification

Acidification is measured in H^+ eqv. and consist of emissions of nitrogen and sulphur compounds, see Figure 3.44, 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%).

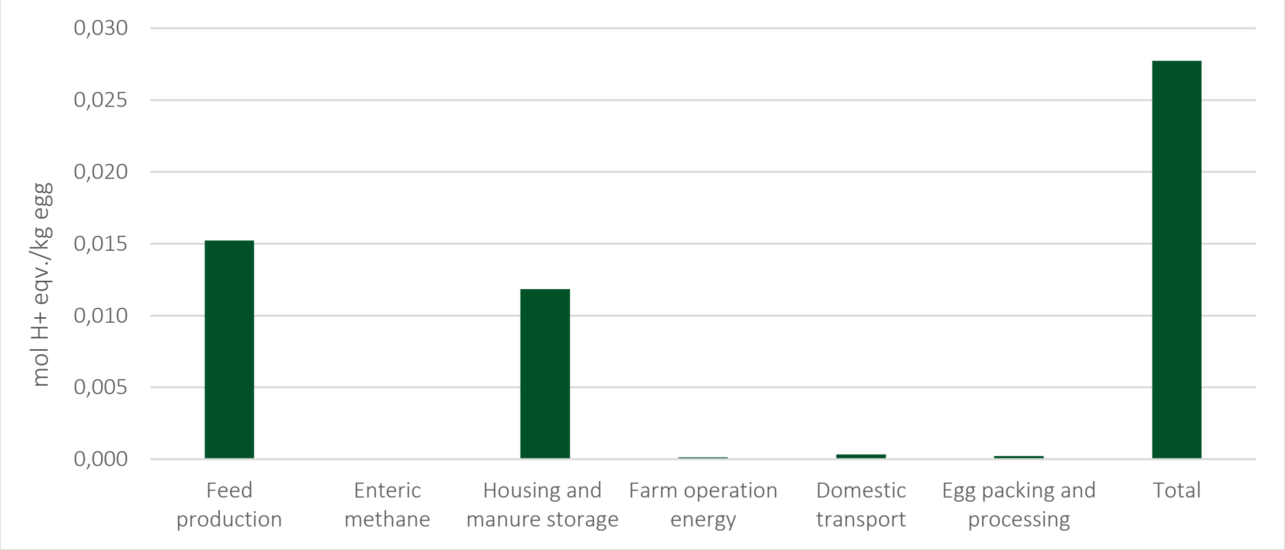

Figure 3.44 Acidification (mol H^+ eqv.) per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant).

3.7.6 Water scarcity

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 3.45 shows that feed production has the largest water scarcity (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.

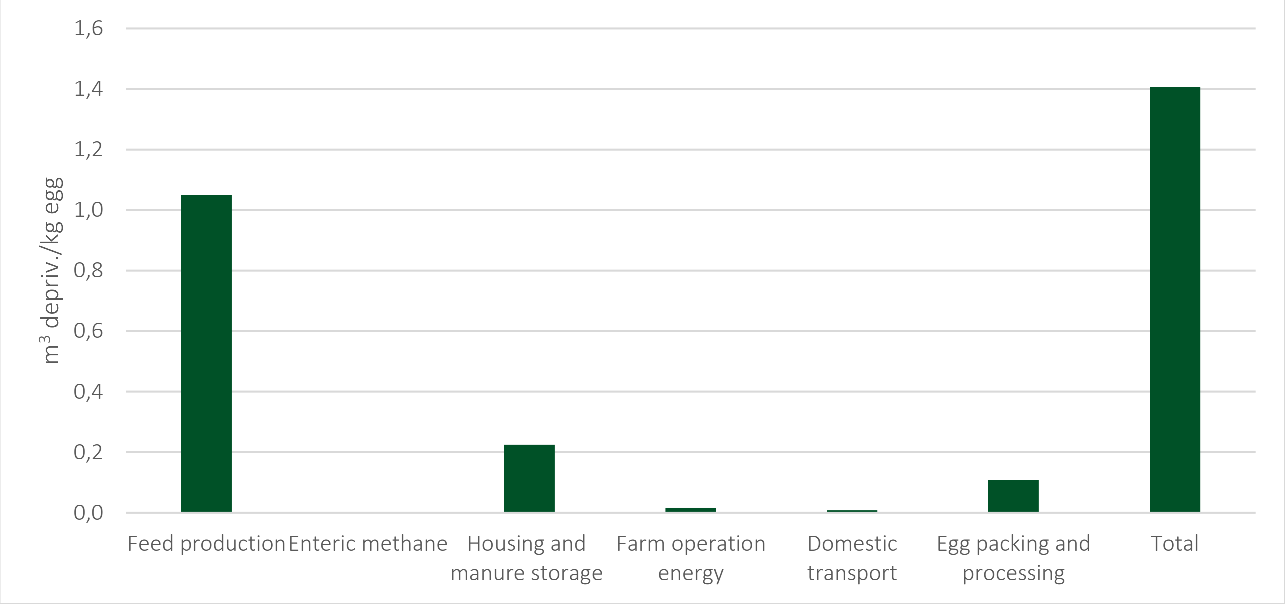

Figure 3.45 Water scarcity (m^3 depriv.) per kg egg through the life cycle (cradle to the gate of the egg packing and processing plant).

4 Conclusion

The results for the environmental impact of meat and egg produced in Norway presented in this report is based on the average production in Norway, providing valuable knowledge of the current situation for the domestic production of meat and egg. These results serve as a documentation of current practice and as a baseline for discussing and evaluating future measures to improve the sustainability of the value chain.

By including several impact categories such as climate change, land occupation, biodiversity, eutrophication, particulate matter, and acidification the report helps minimising the risk of problem shifting as the impact categories are influenced by different parts of the production. However, large variability exists between individual farms, which is not accounted for when assessing the impact from average farms and average production levels. Thus, documenting this variability would be a valuable addition to this report when evaluating measures and future changes in the value chain. The table below shows the total environmental impacts at slaughterhouse gate for all animal species per kg carcass and egg and GHG per kg of protein.

Total environmental impacts from cradle to slaughterhouse gate per kg carcass, kg egg and GHG per kg of protein.

Impact category and unit	Beef dairy cattle	Beef beef cattle	Mutton and lamb	Pork	Chicken	Turkey	Egg
Per kg of carcass and egg							
GHG total (kg CO$_2$ eqv)	21.6	30.0	23.0	3.4	2.3	2.3	1.5
- GHG methane (kg CO$_2$ eqv)	*10.2*	*16.3*	*10.2*	*0.7*	*0.1*	*0.2*	*0.1*
-GHG, nitrous oxide (kg CO$_2$ eqv)	*7.2*	*10.5*	*9.9*	*0.6*	*0.4*	*0.7*	*0.4*
-GHG fossil (kg CO$_2$ eqv)	*3.5*	*2.8*	*2.3*	*1.6*	*1.5*	*1.3*	*0.9*
-GHG LULUC (kg CO$_2$ eqv)	*0.3*	*0.1*	*0.07*	*0.04*	*0.04*	*0.07*	*0.05*
Land occupation, excl. outfields (m^2)	26.6	27.6	23.0	6.5	4.4	6.3	3.6
Biodiversity (PDF)	7.0	-14	-38	4.3	2.9	4.1	2.4
Eutrophication, marine (kg N eqv)	0.05	0.04	0.05	0.01	0.01	0.01	0.01
Eutrophication, freshwater (kg P eqv)	0.014	0.011	0.009	0.0009	0.0006	0.0006	0.0004
Eutrophication, terrestrial (mol N eqv)	1.85	2.50	1.53	0.22	0.12	0.36	0.12
Particulate matter (disease inc.)	2.7E-06	3.8E-06	2.0E-06	4.0E-07	2.0E-07	6.0E-07	2.0E-07
Acidification (mol H+ eqv)	0.41	0.56	0.33	0.05	0.03	0.08	0.03
Water scarcity (m^3 depriv.)	1.8	0.6	0.7	0.5	2.1	1.8	1.4
GHG per kg of protein (kg CO$_2$ eqv)	187	259	258	24	19	18	12

Water usage differences are largely attributed to feed production. Poultry feed, in particular, contains imported ingredients that have significant water impacts due to regional variations in water availability.

In conclusion, the environmental impacts of livestock production in Norway vary significantly across different animal species, with notable differences between ruminants and monogastric animals. For the ruminants dairy cattle, beef cattle and sheep, a large part of the greenhouse gas emissions (GHG) are attributed to enteric methane, with additional contributions from nitrous oxide (N_2O) emissions during housing and manure storage. In contrast, for the monogastric animals pig, chicken, turkey and laying hen, nitrous oxide from use of fertiliser and CO_2 emissions from feed production make up the largest proportion of greenhouse gases. Methane and nitrous oxide emissions from housing and manure storage also contribute, but to a lesser extent.

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.

Biodiversity impacts are in this study assessed based on plant species richness for different types of land use management during feed production. 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. Beef cattle and sheep, on the other hand, source a larger part of the feed from grazing in permanent pasture and outfields. Grazing by beef cattle and sheep tends to enhance biodiversity due to their reliance on permanent pastures. In contrast, 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, it will lead to a net loss in biodiversity Thus, beef and sheep production contribute positively to biodiversity, whereas dairy and monogastric production typically result in a net decline.

The differences in water scarcity are mainly due to feed production. Especially poultry feed contains imported feed ingredients that have water impact because of regional variations in water availability . The AWARE (Available WAter Remaining) method, which factors in water scarcity in each country, highlights the importance of considering regional water use when assessing the overall environmental impact of feed production for monogastric animals.

To conclude- the environmental impacts of livestock production in Norway are highly dependent on the type of species and their respective feeding systems. The findings show the complexity of the environmental footprint of livestock production and highlight the need for targeted strategies that address species-specific challenges to improve sustainability across the value chain.

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

Heifers, birth–calving	LU/herd	23.0[a]	Animalia, 2021a
Bulls, birth –slaughter	LU/herd	14.9[a]	-
Age at calving, heifers	months	26,4	-
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, 2021b
Lambs in Norway at fall	number	745,959	Animalia, 2021b
Sheep slaughtered	number	521,485	Animalia, 2021b
Ewes per herd	number	88.9	Animalia, 2021b
Lamb and lambing			Animalia, 2021b
Lambs born per mated ewe	number	2	Animalia, 2021b
Lambs born alive per mated ewe	number	1.91	Animalia, 2021b
Lambs at fall per mated ewe, excluding bottle lamb	number	1.47	Animalia, 2021b
Lambs at fall per mated ewe, including bottle lamb	number	1.58	Animalia, 2021b
Still born	%	4.4	Animalia, 2021b
Lambs dead before spring pasture	%	3.4	Animalia, 2021b
Lambs dead on spring pasture	%	1	Animalia, 2021b
Lambs dead on summer pasture	%	4.1	Animalia, 2021b
Lambs, birth weight	kg LW	4.8	Animalia, 2021b
Lambs, spring weight	kg LW	18.9	Animalia, 2021b
Lambs, fall weight	kg LW	43.1	Animalia, 2021b
Lambs, carcass weight	kg	19.7	Animalia, 2021b
Lambs, age spring weight	days	42	Animalia, 2021b
Lambs, age fall weight	days	136	Animalia, 2021b
Lambs, age slaughter	days	155	Animalia, 2021b
Yield per ewe	kg	63.7	Animalia, 2021b
Ewe, carcass weight	kg	31.7	Animalia, 2021b
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	proportion	0.12	
Ewes, time on pasture	proportion	0.58	
Lambs for breeding, concentrate	proportion	0.22	
Lambs for breeding, time on pasture	proportion	0.58	
Lambs for slaughter, concentrate	proportions	0.07	
Lambs for slaughter, time on pasture	proportion	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 developed 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.

Table A4 Background data for calculation of net energy for growth and wool at farm and allocation factor

	Unit	Data	Reference
Average herd size:			
Lambs slaughtered	number	159	Animalia, 2021b
Replacement ewes	number	42	Animalia, 2021b
Ewes	number	89	Animalia, 2021b
Lambs:			
Live bodyweight at weaning (6 weeks), (BWi)	kg	18.9	Animalia, 2021b
Live bodyweight at slaughter (BWf)	kg	45.2	Animalia, 2021b
Weight gain, BWf – BWi (WG_{lamb})	kg/ yr	26.3	
Days from weaning to slaughter	days	113	
Constants			
a_{lamb}	-	2.3	EU, 2021; IPCC 2006
b_{lamb}	-	0.40	EU, 2021; IPCC 2006
Net energy growth (NEg)[1]	MJ/day	3.52	
Net energy growth (NEg) lambs at farm	MJ/day	561	
Replacement ewes:			
Live bodyweight at weaning (6 weeks), (BWi)	kg	18.9	Animalia, 2021b
Live bodyweight at 1-year old (BWf)	kg	75.5	Animalia, 2021b
Weight gain, BWf – BWi (WG_{lamb})	kg/ yr	56.6	
Constants			
$a_{replacement\ ewe}$	-	2.1	EU, 2021; IPCC 2006
$b_{replacement\ ewe}$	-	0.45	EU, 2021; IPCC 2006
Net energy growth (NEg)[1]	MJ/day	3.62	
Net energy growth (NEg) replacement ewes at farm	MJ/day	153	
Total net energy growth at farm (NEg)	MJ/day	713	
Wool:			
Lamb	Kg/year	1.1	
Ewe	Kg/year	2.8	
Wool production at farm	Kg/year	471	
Energy value of wool produced (EV_{wool})	MJ/kg	157	EU, 2021; NRC, 2007
Total net energy wool at farm (NE_{wool})	MJ/day	202	
Allocation factor meat[2]	%	78	

1. Net energy for growth (EU, 2021; IPCC 2006): $NEg = \frac{WG_{lamb} * (a+0{,}5b(BWi+BWf)}{365}$
2. Allocation factor (EU, 2021) $\% \, meat = \frac{Energy\ for\ meat}{Energy\ for\ wool+energy\ for\ meat}$

Appendix 1.4 Pork

Table A5 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 A6 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	(Kjos 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 A7 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	(Kjos 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%	(Norwegian Environment Agency, 2022)
Bo: Maximum CH4 producing capacity for manure produced by an animal	m3 /kg of VS	0,36	0,36	0,36	
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 A8 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	(Kjos 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	
Unabated emission factors for NH3-N losses from housing	%	35 %	35 %	35 %	(Norwegian Environment Agency, 2022)
Abatement measures, housing		100 %		100 %	

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