Life Cycle Impacts of Protein-rich Foods for *Superwijzer*

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CE Delft is an independent research and consultancy organisation specialised in developing structural and innovative solutions to environmental problems.
CE Delft's solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

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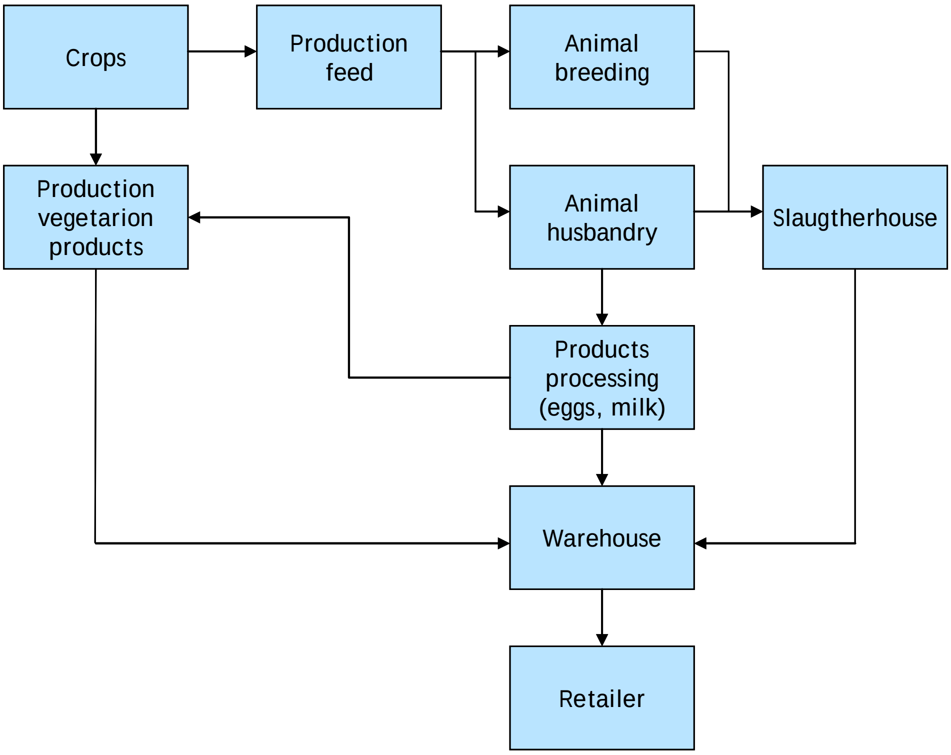
Summary

The *Superwijzer* is the follow-up to the *Vleeswijzer* (Meat Index), which was launched at the end of 2009. Developed by the Varkens in Nood foundation, the *Vleeswijzer* offers consumers information about the environmental and animal welfare impacts of the most common meat and meat alternatives. The *Superwijzer* will enable consumers to make more sustainable choices in the supermarket.

CE Delft has collaborated on the *Superwijzer* by determining the environmental effects of 98 different animal products and animal product alternatives from the farm to the supermarket. Such a wide variety of products were examined in order to not only compare *between* product groups but also *within* product groups. There are currently several different varieties of the same products available in the supermarkets, such as conventional, organic, free-rage options, and it is often difficult for the consumer to assess which products are the most sustainable. The *Superwijzer* will shed light on the differences and thus which assist the consumer in choosing between products.

The Approach
For the environmental assessment the Life Cycle Assessment method (LCA) was used. This method identifies the global environmental effects that are connected to production chains from cradle to grave. The life cycles of all the products are modelled up to the point of retail. Although the products are diverse, there is much overlap between the life cycles. The system boundaries of each life cycle can therefore be summarised by a simplified diagram (see Figure 1).

Figure 1 **General overview of processes that are included in the product life cycles**



The impact assessment for the products in the Superwijzer was carried out using a customised version of ReCiPe (hierarchic) method. The impact categories have been clustered into four main categories:

Nature and Environment (biodiversity): The effects of environmental damage on biodiversity, which is measure in species.yr and the damage expressed in pdf[1].

Human Health: The effects of environmental damage on human health are measured in DALY or disability-affected life years and are measured as endpoints.

Climate Change: Climate change is measured in terms of kg CO_2 eq.

Land Use: Land use, measured in m^2, takes into consideration the physical space that is occupied by a given system.

Results

The results of the environmental assessment of the 98 products are shown in Figure 2 and Figure 3, for biodiversity and climate change, respectively. The bars indicate the environmental impact or damage (larger bars indicate that products are worse for the environment). In Figure 2 the impact on biodiversity is presented as a percentage of the product with the highest score (Brazilian beef is set at 100%). In Figure 3 the results for impact on climate change are presented on a relative scale, as a function of the highest score for climate change.

[1] The biodiversity unit, PDF, or potential disappeared fraction, is a common unit used for measuring the effect of emissions and human activity on the extinction of species.

Figure 2 Categorised scores for impact on biodiversity. The coloured bars indicate the low impact (green), average (yellow) and high (red) scores per category. The number of products represented in each category is given beside the scores

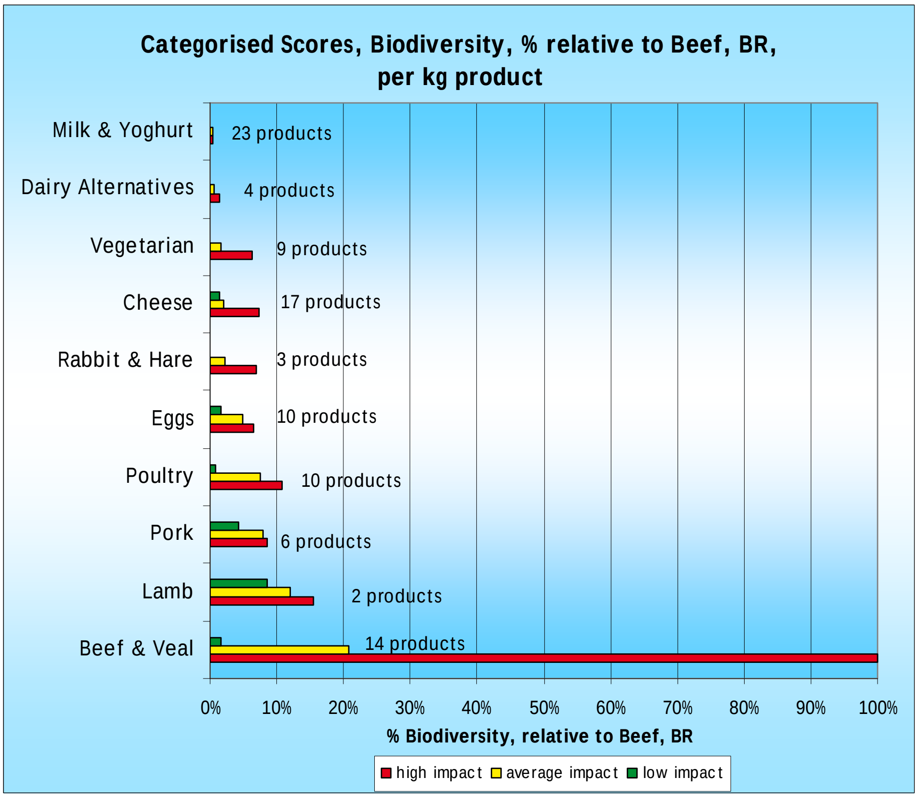
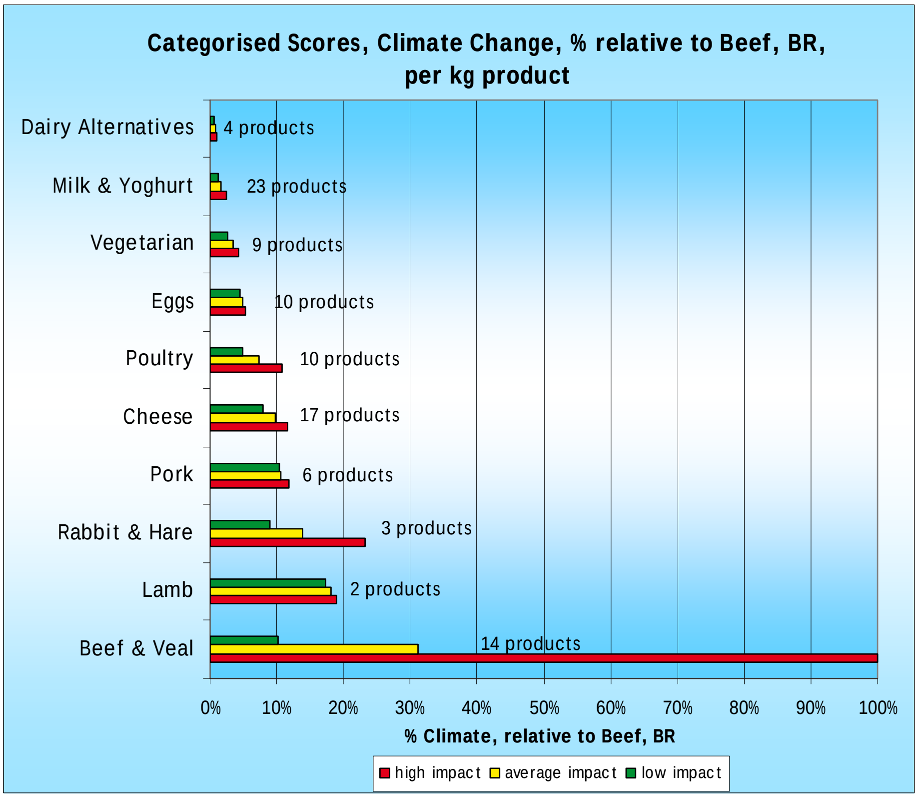


Figure 3 Categorised scores for impact on climate change. The coloured bars indicate the low (green), average (yellow) and high (red) scores per category. The number of products represented in eachcategory is given beside the scores



The results from the *Superwijzer* show substantial differences between the lowest and the highest scoring products, particularly in terms of the effects on biodiversity. At the extreme, the highest scoring product (Brazilian beef) has a biodiversity score of over 3,000 times that of the lowest product (Dutch hare). Also within the product group 'Beef and Veal' there is still a difference of factor 10 between the lowest and highest score. In terms of the effects on climate change, Brazilian beef has a score that is about 36 times higher than Quorn, a meat alternative. Although these scores only illustrate the upper and lower scores, there is a distinct clustering of product types. In terms of an approximate product ranking, beef and veal rank worst, followed by other meat types (the order depends on the impact category used), followed by eggs and cheese, and finally, the meat substitutes (vegetarian), milk and yoghurt and dairy alternatives rank best.

There are also distinct variations in certain product categories. Beef and veal have by far the largest range in scores both for biodiversity and climate change. The lowest scoring products are minced and cut beef originating from spent dairy cows, while the highest scoring product is Brazilian beef. Another product category with a large variation is 'rabbit and hare', which has a relatively low scores for Dutch hare and relatively high score for rabbit. Some product groups, such as pork have very little variation in the environmental impact within the group. Large variations in environmental impact within product groups can have an effect on the ranking of a particular product group, such that general statements regarding the scores of specific groups are more difficult to be made.

In conclusion, choosing products with a low environmental impact will lead to significant reductions in the environmental impact of an individual's diet. It is expected that by raising awareness, consumers will have a stronger drive to choose environmentally favourable alternatives.

1 Introduction

1.1 Background

The *Vleeswijzer* (Meat Index) was launched at the end of 2009. Developed by the Varkens in Nood foundation, the *Vleeswijzer* offers consumers information about the environmental and animal welfare impacts of the most common meat and meat alternative products. This guide enables the consumer to make a well-informed decision about their product purchases.

Since its release, a great deal of experience with the *Vleeswijzer* has been acquired and an update is to be conducted. This update will not only be a change in design, where the current wallet-sized card will be replaced with a digital application (an App for smartphones) with the potential of allowing users to scan product barcodes, but the goal is also to expand the list of product types and to include the most recent scientific developments in the product assessments.

Varkens in Nood has asked CE Delft to collaborate on this update to the *Vleeswijzer,* which will be known as the *Superwijzer* and will be referred to as such here on end. CE Delft's contribution will include determining the environmental effects of meat, meat alternatives, dairy and additional product types. Other parties will contribute the analysis of animal welfare.

1.2 Purpose

The main purpose of this project is to map out the environmental impacts of various types of meat, meat alternatives, dairy products and eggs over the entire product life cycle up to the point of sale to the consumer. These impacts per kilogram of product (excluding packaging) are input to the *Superwijzer* App. The consumer interface of the App will only be briefly discussed in this report, as the focus will be on the results.

1.3 This Report

Given that this report is a handbook to the iPhone App instead of acting as the end product of this study, this report is structured somewhat differently than a typical life cycle assessment study. Chapter 2 defines the boundaries and scope of the study as well as the methodology used for assessing the environmental impacts of the product systems. Chapter 3 summarises the major references and assumptions used in modelling the product lifecycles. Chapter 4 illustrates a number of representative products in diagram form. Finally, Chapter 5 delves into some of the implications of the results of the study. A summary of all the results are available in Annex A, while each product is described in greater detail in Annex B. Further explanations for land use change are discussed in Annex C.

2 System Definition

2.1 Goal and Scope

The end goal of this study is to update and expand the current *Vleeswijzer* such that the consumer will be able to make informed purchasing decisions amongst various meat, dairy, eggs, and alternative products, in terms of the environmental and animal welfare performance of those products. In order for this information to be accessible and convenient for the consumer, Varkens in Nood will be creating an iPhone App. This iPhone App will allow the consumer to have an interactive version of the *Superwijzer,* which will allow them to have product information available while shopping.

2.2 Product Inventory

As mentioned in the introduction, *Superwijzer* will be comprised of several more product types than were included in the former *Vleeswijzer*. The inventory list is given below in Table 1.

Table 1 Product types included in ***Superwijzer***

Product	
Meat and Meat Substitutes	
Beef	**Pork**
Beef, Argentina	Pork, conventional, Netherlands
Beef, Brazil	Pork, organic, Netherlands
Beef, Germany	Pork, AH 1 star, Netherlands
Beef, Ireland	Pork, AH 2 star, United Kingdom
Beef, Poland	Pork, Jumbo bewust, Netherlands
Beef, conventional, Netherlands	Pork, Milieukeur, Netherlands
Beef, organic, Netherlands	**Poultry**
Beef, nature, Netherlands	Chicken, Brazil
Beef, cuts, Netherlands (spent dairy cows)	Chicken, label rouge, France
Beef, mince, Netherlands (spent dairy cows)	Chicken, conventional, Netherlands
Beef, mince, organic, Netherlands (spent dairy cows)	Chicken, organic, Netherlands
Veal, rosé, conventional	Chicken, corn, Netherlands
Veal, rosé, organic	Chicken, scharrel, Netherlands
Veal, rosé, 1 star (van Drie)	Chicken, volwaard, Netherlands
Vegetarian Meat Alternatives	Duck, Netherlands
Falafel, Tivall	Turkey, Brazil
Groentenschijf, Vivera	Turkey, Netherlands
Meatless	**Lamb**
Quorn, mince	Lamb, conventional
Tofu, certified	Lamb, organic
Tofu, certified, organic	**Rabbit/Hare**
Tofu, uncertified	Rabbit, Netherlands
Tofu, uncertified, organic	Hare, Argentina
Valess, schnitzel	Hare, Netherlands

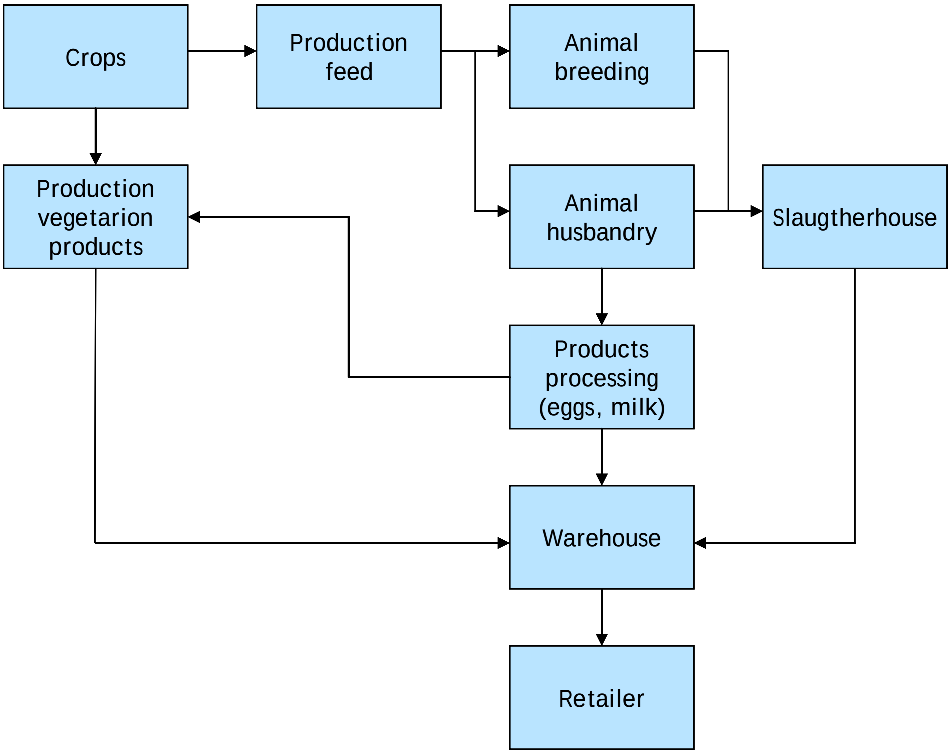
Product	
Dairy and Eggs	
Milk	**Cheese**
Milk, cow, whole milk, conventional	Cheese, cow, old, conventional
Milk, cow, whole milk, organic	Cheese, cow, old, organic
Milk, cow, whole milk, pasture (weidegang)	Cheese, cow, old, pasture
Milk, cow, semi-skim, conventional	Cheese, cow, medium, conventional
Milk, cow, semi-skim, organic	Cheese, cow, medium, organic
Milk, cow, semi-skim, pasture (weidegang)	Cheese, cow, medium, pasture
Milk, cow, skim, conventional	Cheese, cow, young, conventional
Milk, cow, skim, organic	Cheese, cow, young, organic
Milk, cow, skim, pasture (weidegang)	Cheese, cow, young, pasture
Milk, cow, buttermilk, conventional	Cheese, goat, old, conventional
Milk, cow, buttermilk, organic	Cheese, goat, old, organic
Milk, cow, buttermilk, pasture	Cheese, goat, medium, conventional
Milk, goat, whole milk, conventional	Cheese, goat, medium, organic
Milk, goat, whole milk, organic	Cheese, goat, young, conventional
Milk, soy, certified	Cheese, goat, young, organic
Milk, soy, certified, organic	Cheese, buffalo, mozzarella, Italy
Milk, soy, uncertified	Cheese, cow, mozzarella
Milk, soy, uncertified, organic	**Eggs**
Yoghurt	Eggs, chicken, battery
Yoghurt, cow, whole, conventional	Eggs, chicken, organic
Yoghurt, cow, whole, organic	Eggs, chicken, enriched cage
Yoghurt, cow, whole, pasture	Eggs, chicken, barn (scharrel)
Yoghurt, cow, semi-skim, conventional	Eggs, chicken, 1 star (scharrel +)
Yoghurt, cow, semi-skim, organic	Eggs, chicken, Rondeel
Yoghurt, cow, semi-skim, pasture	Eggs, chicken, free range
Yoghurt, cow, skim, conventional	Eggs, chicken, grass
Yoghurt, cow, skim, organic	Eggs, chicken, omega-3
Yoghurt, cow, skim, pasture	Eggs, chicken, 60% corn

2.3 System Boundaries

2.3.1 Extent of the Life Cycle

As stated in the introduction the life cycles of all the products are modelled up to the point of retail. Although the products are diverse, there is much overlap between the life cycles and therefore the system boundaries of each life cycle can be summarised by a simplified diagram (see Figure 4).

Figure 4 General overview of processes that are included in the product life cycles



Within each step of this broader overview, more specific system boundaries can be further defined:

– Crops:
  - land use type;
  - land transformation;
  - fertilizer application, including animal manure;
  - pesticide application;
  - energy use (diesel and electricity).
– Production of feed:
  - energy use;
  - transportation.
– Animal husbandry:
  - animal breeding for some animal types, however this is not included for certain animal types as a result of an absence of data (such as for turkeys and ducks[2]);
  - feed inputs;
  - animal emissions (enteric fermentation, ammonia and particulate from barns/sheds, etc.);
  - emissions from manure handling and paddock manure (emissions of application of manure on crops included in crops);
  - direct land occupation of indoor/outdoor housing space;
  - transport of animals (including long distance);
  - energy use of buildings.
– Processing of animal products (milk, cheese, etc.):
  - energy use in production facility.

[2] Turkeys and ducks husbandry systems are assumed to be similar to that of broiler chickens. The impact of the animal breeding system on a kg of chicken is quite small (around 2%), thus the impact of breeding on the turkey and duck systems are also assumed to be almost negligible.

- Production of vegetarian products:
  - energy use in production facility.
- Slaughterhouse:
  - energy use in slaughter plant.
- Warehouse:
  - energy use of lighting and refrigeration.
- Retail:
  - energy use of refrigeration.
- Transport included between all steps of processing in chain.

2.3.2 Allocation and Cut-off

Agriculture, particularly animal agriculture, can become rather complex to model accurately. There are many reasons for this complexity, much having to do with the fact that farms can be very different and one often has to rely on average systems (see Section 2.3.3 for similar information). However, some of the complexity is derived from the multiple outputs from processes and the multiple usages of these outputs, which can make the product focused goals of a life cycle assessment a daunting task. In order to solve this problem, various methods where employed:

- Applying a cut-off for manure:
  Manure is generated in most of the product chains and leads to unwanted environmental impacts. At the same time, manure is applied as a useful product, as fertilizer or as an energy source. A cut-off approach is a applied for manure that is generated and managed within barns or stables. Emissions from management, as well as paddock manure, are included to the animal system, but emissions from later applications are allocated to the crop system or energy system involved.

- The allocation of crop products:
  Crop types can often be processed from their constituent parts (proteins, oils, fibres, etc.) into multiple products. As such, a product using only one part of the plant should not have to encompass the environmental impact of the entire plant. In order to be able to narrow in on a specific crop product, an allocation approach based on economic value was applied.

- The allocation of animal products:
  All throughout the animal agriculture chain, various products and co-products result. For example, in the case of broiler chickens, the breeder chickens produce fertile eggs which become the future broiler and replacement breeder chickens. In addition to fertile eggs these breeders also produce edible eggs and at the end of their life their spent bodies are slaughtered for meat. Since these are also products (and not waste), it is import to assign some of the environmental burden to these products as well. In this study this was accomplished using economic allocation, that is, both the product quantity and its unit market price were used to determine the relative share of the burden that these products should carry. This type of allocation was used:
  - at the farming stage (animals for meat, animals for breeding, useful products (milk, eggs), spent animals);
  - at the slaughter stage (high quality cuts, by-products).

- The allocation of raw milk to dairy products:
  According to the IDF foot printing methodology (IDF, 2010), raw milk is allocated to products of dairy processing via milk solids content.

2.3.3 Limitations and Exclusions

Excluded Processes

While efforts were made to include all relevant aspects of the life cycles of the various products, not everything could be included. The reason for this exclusion has to do with the relative low impacts of some aspects as well as the high degree of uncertainty in these data. The excluded aspects of the life cycles were as follows:

- Farm infrastructure:
  - buildings;
  - equipment;
  - vehicles.
- Employee commuting.
- Office activities.
- Veterinary care of animals, including the use (and the effects) of antibiotics.
- Materials on the farms, slaughterhouses and production facilities:
  - packaging materials for crops;
  - general materials used;
  - transport packaging;
  - packaging of products.
- Non-excretion waste:
  - feed packaging;
  - the removal and treatment of animal carcasses at the farm;
  - wastewater;
  - production waste.
- Emissions of heavy metals due to fertilizer application (chemical and manure).
- Additives in animal feed:
  - filler;
  - vitamins;
  - antibiotics.

Limitations of this Study

As mentioned in Section 2.3.2, the products modelled in this study relied heavily upon (national) average data. In the case of similar products, i.e. organic chicken and conventional chicken, extrapolations and estimations were made in order to be able to model these differences. Much of the emissions data was only available as average data for specific animal types, ages and countries; however no additional information regarding the statistical accuracy of this data was given by the organisations that publish the statistics. In particular, proxies were made based on known data for other product types for the products for which little to no data exists in the public domain. Examples of these proxies include emissions data for Brazilian turkey, travel distances within Argentina, Brazil and Israel.

While these limitations could appear to have large effects on the results of the study, the actual effects are most likely not significant. In the case of extrapolation of emissions data for similar products, the actual emissions of animals in specific animal husbandry systems will differ very slightly from average data if at all. Since the average data used will be from the same animal species, the animals themselves will on average release the same amount of emissions. The only difference may be the location of the emissions release, for example, whether or not manure is deposited in a barn or at a low concentration outdoors. In the case of unknown transportation distances, transportation has an overall small contribution to the environmental impacts of a particular product, thus slightly under or overestimations will not affect the overall impact.

2.4 Impact Categories

A customised version of ReCiPe (hierarchic endpoint) method is used in the assessment of the environmental impact of the various product types. The impact categories have been clustered into four main categories:

- Nature and Environment:
  The effects of environmental damage on biodiversity (measures in species.yr or PDF, see Section 2.4.1 for more information). These include the impact on ecosystems:
  - terrestrial acidification;
  - freshwater eutrophication;
  - terrestrial ecotoxicity;
  - freshwater ecotoxicity;
  - marine ecotoxicity;
  - effects of climate change on ecosystems;
  - agricultural land occupation;
  - urban land occupation;
  - natural land transformation.

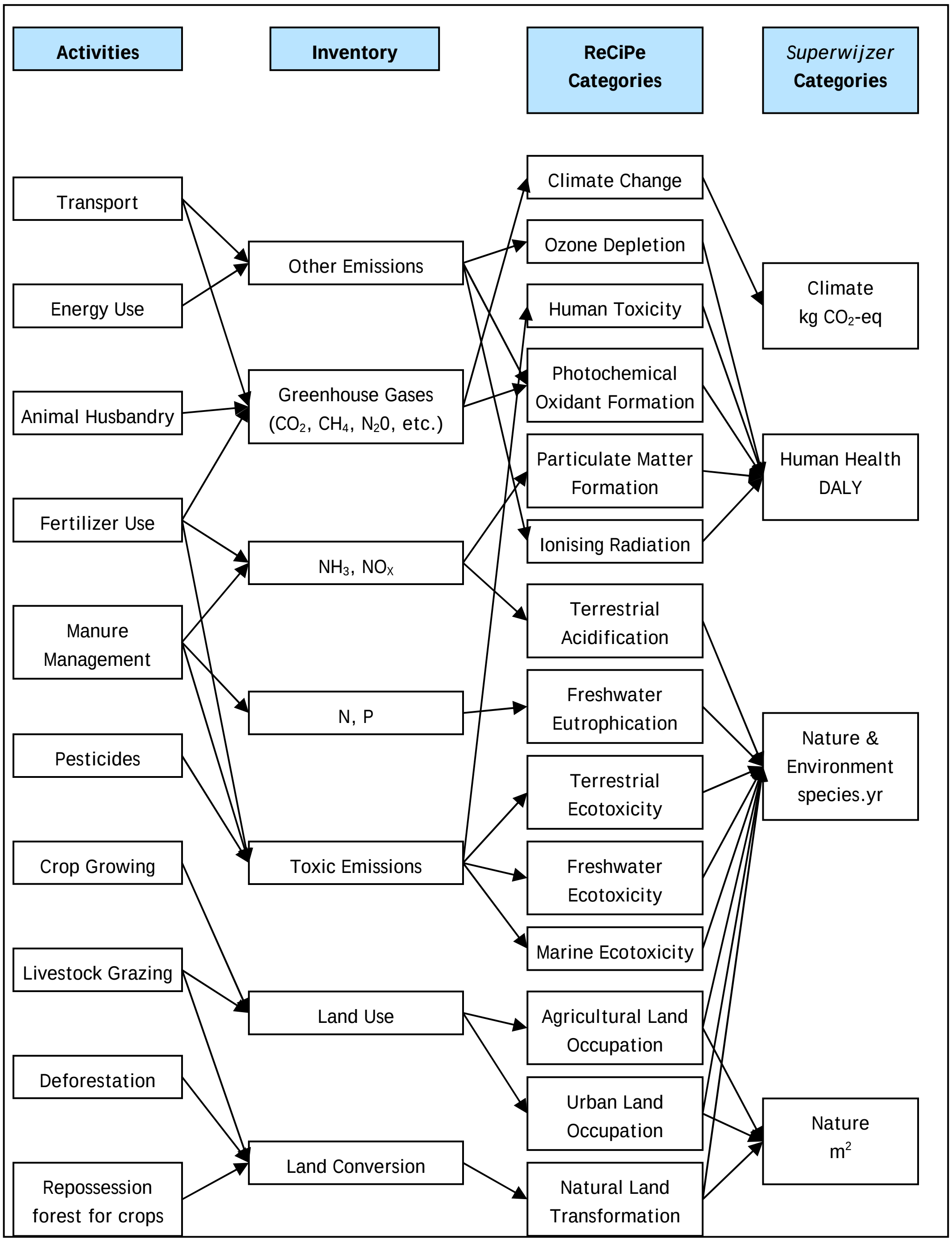
- Human Health:
  The effects of environmental damage on human health are measured in DALY or disability-affected life years and are measured as endpoints. The following midpoint impact categories are included:
  - ozone depletion;
  - human toxicity;
  - photochemical oxidant formation;
  - particulate matter formation;
  - ionising radiation;
  - effects of climate change on human health.

- Climate Change:
  Climate change is measured in terms of kg CO_2 eq. and includes the following categories:
  - climate change (process);
  - climate change, land transformation.

- Land Use:
  Land use, measured in m^2, takes into consideration the physical space that is occupied by a given system. It includes the follow categories:
  - agricultural land occupation;
  - urban land occupation.

Figure 5 shows the activities that take place in agricultural life cycles and their fates and effects on environmental impact categories.

Figure 5 **Fate of emissions created in agricultural system**



2.4.1 Impacts of Land Transformation

Land transformation is included in the inventory in terms of hectares of land transformed. This leads to biodiversity losses. The biodiversity impact per hectare of land transformation is based on the ReCiPe Endpoint (H) methodology and is expressed in Potentially Disappeared Fraction (PDF) or species per m^2 year. PDF is defined as the potential disappeared fraction of species lost, which can attributed by various human activities. In addition, estimations have been made for additional land types. The inventory also includes emissions of greenhouse gases as a result of land transformation, in terms of ton CO_2 equivalent emissions per hectare. In Annex C, the details of inventory and impact assessment are given.

3 Data Sources

Given the complexity of the product life cycles and the large range in geographic coverage needed, a multitude of sources were used in the models. While some sources were used for single pieces of data or in order to assist in making estimations, other sources were used for large portions of modelled processes. The sources that were used most often will be mentioned below.

3.1 Primary and General

The *Vleeswijzer*, which was largely based on the study published by Blonk et al. (2008), is the basis for the *Superwijzer*. In particular, the crop production data, feed production data and animal husbandry system data for non-Dutch production systems were used.

3.2 Animal Feed and Plant Ingredients

At the crop stage, fertiliser use (NPK), diesel and electricity use, nitrogen fixation rates, proportional geographical land use per hectare, transportation distances and modes, were obtained from Blonk (2008), while crop yields were obtained from FAOSTAT (2009). Methane emissions of palm oil mill effluent are included. Pesticide application for conventional crops was taken from PPO (2009) and from Ecoinvent (2007) (for crops not listed in PPO, 2009), in addition to the manure application on organic crops. The energy use to produce feed concentrate was taken from a study by Sevenster and Hueting (2007).

The allocation for co-products for feed crops is as follows:
- Soy:
  - soybean meal: 74% weight, 70% of revenue;
  - soybean hulls: 8% weight, 1% of revenue;
  - soybean oil: 18% weight, 29% of revenue.
- Oil palm:
  - palm kernel meal: 7% weight palm plant, 6% of palm kernel revenue;
  - palm kernel oil: 7% weight palm plant, 94% of palm kernel revenue;
  - palm oil: 86% weight palm plant, 100% of palm fruit revenue.
- Rapeseed:
  - rapeseed meal: 59% weight, 29% of revenue;
  - rapeseed oil: 41% weight, 71% of revenue.

The vegetarian products were modelled using a number of main sources. A few of the products, the Vivera Groentenschijf (vegetable patty), the Quorn Mince, and the Tivall Falafel were largely taken from Broekema and Blonk (2009), a study about the environmental impact of meat alternatives. In addition, Blonk et al. (2008) was used to model soymilk and Meatless.

3.2.1 Land Use, Land Transformation and Related Emissions

The land use is based on the yields (primarily from FAO, year 2009). For soy, oil palm and coconut, land transformation of natural land is included, as well as LUC emissions. This is described in Annex C.

Greenhouse gas emissions of land use result from the following sources:

- Enhanced/diminished carbon sequestration: for managed grasslands, the sequestration of carbon can be higher than natural background levels, for cropland there is typically a loss of carbon from soil, reducing to zero flux over time (see e.g. JRC, 2010). These emission sources/sinks are not included.
- Emission of N_2O of mineralisation of peat soils (histosol) in Dutch pasture systems is included (Alterra et al., 2006).
- Emission of CO_2 of oxidation of peat soils in Dutch pasture systems is included (CML, 2007).
- Emission of CO_2 and N_2O of peat soils for oil palm is included.
- Uptake of methane in peat soils is excluded.
- Mineralisation of other soils is excluded.

3.3 Animal Emissions

The emissions caused by the animals in the livestock systems were modelled on many different fronts: the methane released through enteric fermentation; the methane, nitrogen, phosphorus and potassium released to the environment in manure; and the ammonia and particulate matter levels inside barns/sheds. These processes were modelled using the following sources:

- Enteric fermentation
  - GHG National Inventory Reports, 2010 for:
    - The Netherlands (PBL, 2010);
    - The United Kingdom (AEA Technology, 2010);
    - Ireland (EPA Ireland, 2010);
    - Poland (KASHUE-KOBiZE, 2010);
    - Germany (UBA, 2010);
    - Italy (ISPRA, 2010).
  - Condor et al. (2008);
  - ERG and PA, 2009;
  - Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).
- Methane from manure handling:
  - GHG National Inventory Reports, 2010 for:
    - The Netherlands (PBL, 2010);
    - France (CITEPA, 2007);
    - The United Kingdom (AEA Technology, 2010);
    - Ireland (EPA Ireland, 2010);
    - Poland (KASHUE-KOBiZE, 2010);
    - Germany (UBA, 2010);
    - Italy (ISPRA, 2010).
  - Second National Communication, 2010 for:
    - Argentina (República Argentina, 2007).
  - Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).
- N-content in manure:
  - GHG National Inventory Reports, 2010 for:
    - The Netherlands (PBL, 2010);
    - France (CITEPA, 2007);
    - The United Kingdom (AEA Technology, 2010);
    - Ireland (EPA Ireland, 2010);
    - Poland (KASHUE-KOBiZE, 2010);

    - o Germany (UBA, 2010);
    - o Italy (ISPRA, 2010).
  - Second National Communication, 2010 for:
    - o Brazil (MCT, 2008).
  - Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) for N related emissions (default emission factors).
- Phosphorus and potassium emissions:
  - CBS, 2009a for content in manure;
  - Emissions only of phosphate leaching.
- Ammonia and particulate matter emissions in barns/sheds:
  - InfoMil, 2010.

3.4 Farming Systems

In order to model a typical farming system, data regarding the animal population, land use, production period and feed types and amounts needs to known. The farming systems required for the products that include animal products were all modelled using a few main sources. The starting point was Blonk et al. (2008), but much of the data was updated and supplemented with data from WUR (2010). The data used from Blonk et al. (2008) and KWIN (2010) includes:

- the number and age groups of animals in a given farming system;
- typical mortality rates (premature death);
- type and quantity of food used throughout production period;
- types, amounts and economic value of products leaving system;
- energy use in barns/sheds (electricity price = 0.087 Euro/kWh);
- land use through grazing and space occupied by barns/sheds;
- breeding systems required to produce production animals (which includes the above data).

3.4.1 Land Use and Transformation

In terms of quantifying the specific amount of land occupied for a given farming system, particularly the non-conventional products, sources such as Dierenbescherming (2011) and Voedingscentrum (2010) were used. Land use for animal husbandry consists of grazing paddocks, stables (indoor space) and outdoor confinement areas, such as for chickens and buffalo. These types of land use are modelled as:

- Grazing paddocks:
  - Europe: occupation of intensive pasture and meadows;
  - conservation areas: occupation of extensive forest;
  - Argentina: occupation of extensive pasture and meadows.
- Stables (indoor space): occupation of industrial area.
- Outdoor confinement areas: occupation of industrial area with vegetation.

Land use transformation for animal husbandry is only applicable in the case of beef cattle in Brazil. This is a complex issue, as cattle ranching may be the first activity following deforestation, but soy cultivation can follow soon afterwards, thus displacing existing cattle pasture. The approach followed is described in Annex C.

3.5 Slaughter and Processing

The energy use and the types, amounts and allocation of meat output for each animal type were taken from Blonk et al. (2008). The data for turkeys (which were not included in the 2008 study) were taken from Blonk (2007). Proxies taken from Blonk et al. (2008) were made for certain uncommon animal types, for which slaughter data could not be found.

For dairy, a large fraction of the data on energy for processing is derived from IPPC (2006). Allocation of raw milk to final products is based on milk solids content (according to IDF, 2010).

3.6 Transport, Distribution, Storage and Retail

3.6.1 Transport of Live Animals

With the exception a certain localised systems, large-scale transport of livestock throughout Europe is commonplace. In order to properly estimate the typical transportation distances required for transporting breeder animals to breeding facilities, animals from breeding facilities to production facilities and from production facilities to slaughter, CBS (2009b) and Kroeze (2008) were used. These calculations involved using statistics on the proportion of animals travelling from one country to another for a given animal type and then based on an average driving distance between countries, calculating a (weighted) average distance. In order to model the transportation of livestock by ferry between the British Isles, Ireland and continental Europe, Makela (2009) and IMO (2009) were used.

For the transport of livestock outside of Europe, in the case of beef cattle in Argentina and Brazil and chickens and turkeys in Brazil, other data sources (da Silva, 2008 and Cederberg et al., 2009) in combination with Google maps and port to port distance calculators (Portworld, 2011) were used to estimate typical distances.

3.6.2 Distribution, Storage and Retail of Products

After slaughter and/or processing, the products are transported in order to reach the retailer. This long transportation chain can involve refrigerated trucks, refrigerated (reefer) container ships, chilled or freezer warehouses before finally reaching the retailer refrigerator or freezer. The estimation of the energy use and other environmental impacts (e.g. possible release of HFCs from refrigeration systems) of this journey involves an examination of both the energy density of the logistics, the time spent in transit or storage and the distance travelled. The following sources were used to model the transport logistics:

- Transport distances from slaughterhouse to retailer in the Netherlands:
    - da Silva, 2008;
    - Cederberg et al., 2009;
    - Google Maps;
    - Portworld, 2011.
- Warehouse energy use and stocking density:
    - Duiven and Binard, 2002;
    - FAO, 1991.
- Refrigerated transport:
    - IMO, 2009;
    - Cederberg et al., 2009;
    - Faber et al., 2009.

– Refrigeration in supermarkets:
  - Teunissen et al., 2009;
  - NRC, 2009.

3.7 Assumptions

Throughout this study, assumptions were made regarding the product systems and their relative differences. Given the number of product types and the extent of each product life cycle, the assumptions are numerous. For ease of reading these are presented in Table 2.

Table 2 Summary of assumptions made in this study

Product or Process	**Assumption**
Crops and Animal Feed	
Average crop yields	Based on yields of the top 90% in a specific region according to FAO
Proportions of ingredients in Tivall falafel	Ingredients from label, proportion estimated based on order on label and Broekema and Blonk, 2009
Proportions of ingredients in Vivera Groentenschijf	Ingredients from label, proportion estimated based on order on label and Broekema and Blonk, 2009
Energy use for falafel is assumed to be the same as Vivera Groentenburger (from Broekema and Blonk, 2009 study)	
Organic feed	Same ingredient proportions as conventional, except with organic ingredients
Animal Husbandry	
Emissions and feed requirements of breeding not included for following animal types, due to lack of data:	Turkey Duck
Population of beef in nature reserves	Calculated based on the populations of a few herds in Kuit and van der Meulen (1997)
Slaughter and Processing	
% useable meat from rabbit and hare carcasses	50%
Animals types for which the same slaughter energy requirements as chicken are used	Turkey Duck Rabbit Hare
Animals raised in South America are assumed to be slaughtered there	Electricity use at slaughterhouse is from the Brazilian or Argentine grid
Transport, Distribution, Storage and Retail	
Distances in the Netherlands	Meat and meat alternatives: 100 km from Rotterdam to warehouse, 100 km from warehouse to store Dairy products: 50 km from goat milk farm to dairy processor 35 km from cow milk farm to dairy processor
Number of meat packages per metre of refrigerator/freezer	5 wide, 4 deep, 7 high = 140
Number of cartons per metre of refrigerator	10 wide, 5 deep, 6 high = 300
Turnover rate of poultry in supermarket	4 days (based on Belgian source)

Product or Process	Assumption
Turnover rate of pork products in supermarket	2 days (based on Belgian source)
Turnover rate of beef products in supermarket	2 days (based on Belgian source)
Turnover rate of rabbit/hare meat in supermarket	15 days in freezer
Turnover rate of lamb in supermarket	3 days
Turnover rate of milk in supermarket	4 days
Turnover rate of cheese in supermarket	14 days
Turnover rate of vegetarian meat alternatives	3 days
No refrigeration assumed for whole eggs	
Number of days in frozen warehouse	30 days
Number of days in chilled warehouse	3 days
Refrigerated trucks used in transport in Europe	Lorry >32t (Euro 4), with 30% extra energy use for refrigerated trucks
Refrigerated trucks used in South America	Lorry >32t (Euro 4), with 25% extra diesel use based on overloading, 30% above that for refrigerated trucks
Animal transport in South America	Lorry 16-32t (Euro 3), with 25% extra diesel use based on overloading
Animal transport in Europe	Lorry 16-32t (Euro 4)
Day-old egg transport in South America	Lorry 16-32t (Euro 3) + 10% extra fuel use, with 25% extra diesel use based on overloading
Day-old egg transport in Europe	Lorry 16-32t (Euro 4) + 10% extra fuel use
Refrigerated cargo ship	Refrigerated cargo (reefer)
Live animal transport, ferry	Ro-ro ship

4 Illustrative Process Chains

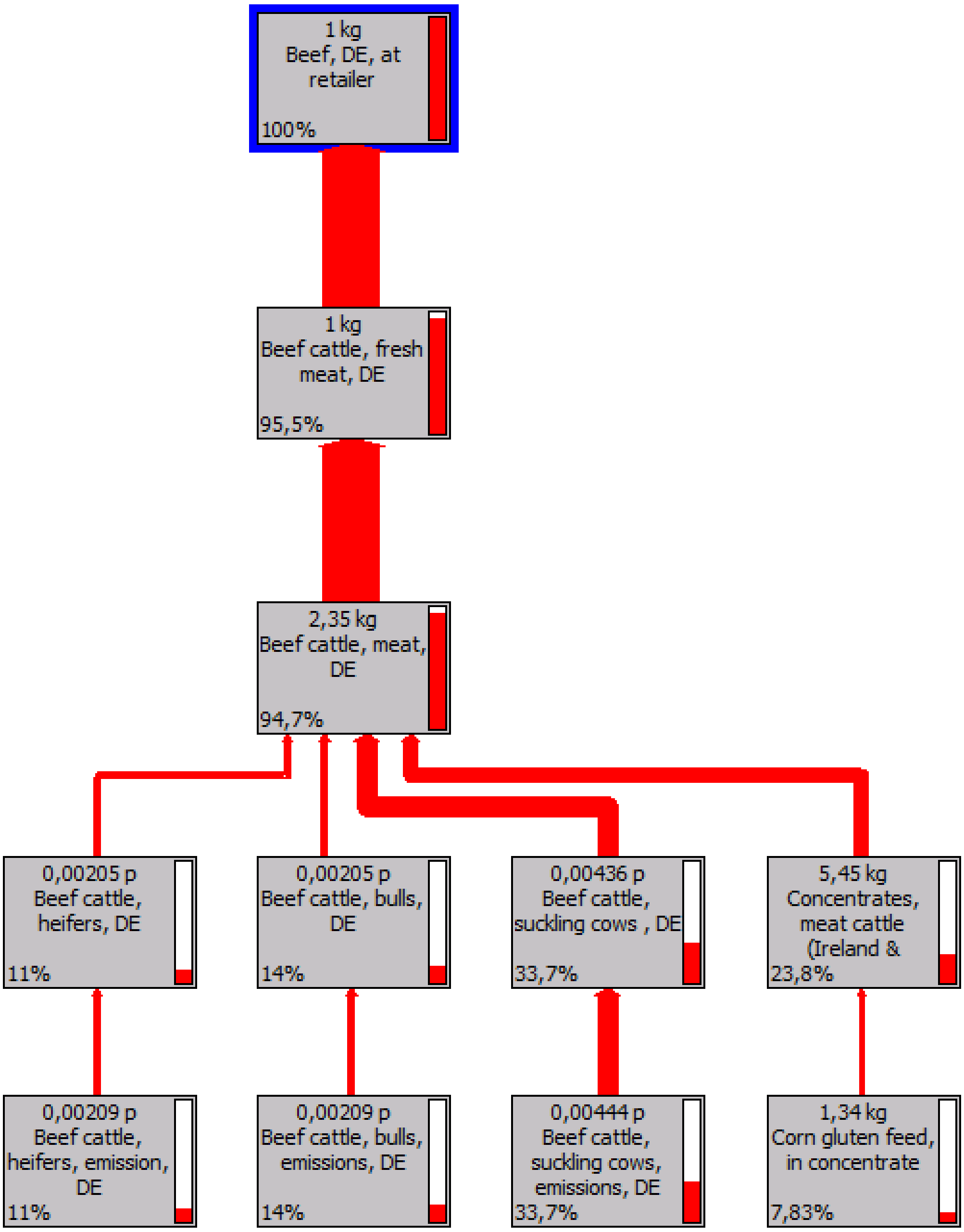
The inventory data as discussed in Chapter 3 were then used as input for impact analysis using characterization factors of the Recipe (H) method. The environmental impacts per kilogram for each product are listed in Annex A. In Annex B, the most relevant sources of impacts in each product life cycle are discussed. The impact categories are:
– Nature and Environment (in PDF or species.year);
– Climate Change (in kg CO_2);
– Human Health (in DALY);
– Land Use (in m^2).

In this section, a few sample process networks will be shown in order to illustrate how the product chains are constructed. Process networks for the most representative or illustrative product and impact category from a product group will be shown, such that each of the final impact categories are represented. It also important to mention that process networks can contain hundreds of sub-processes, but for practical reasons cut-offs have been made. The chosen cut-offs are aimed at representativeness for each product chain and as such the process networks may have varying numbers of sub-processes.

4.1 Meat

A process network for German beef (1 kg at retailer) is shown in Figure 6 for climate change.

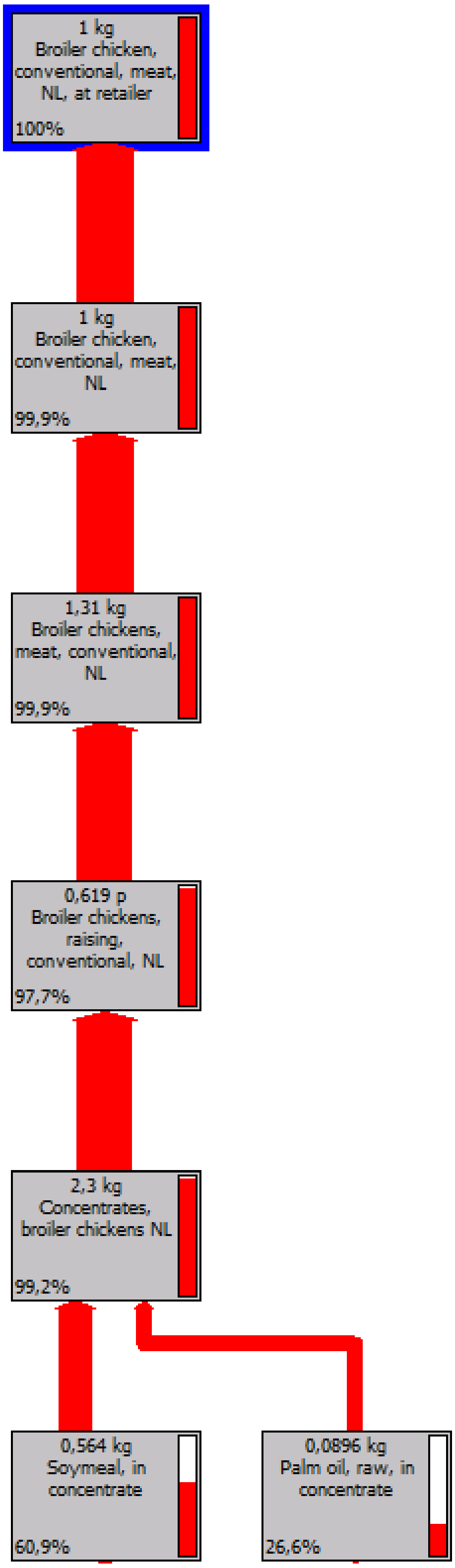
Figure 6 Process network for 1 kg German beef at the point of retail, relative effects on Climate



As shown in Figure 6, more than 50% of the impact to climate change is a result of the methane emissions from enteric fermentation. Another important contribution is the concentrates, which account for more than 20% of the contribution to climate change.

Figure 7 shows the effects to Nature and Environment from 1 kg conventional Dutch chicken at the point of retail.

Figure 7 **Process network for 1 kg conventional Dutch chicken at the point of retail, relative effects on Nature and Environment (species.yr)**

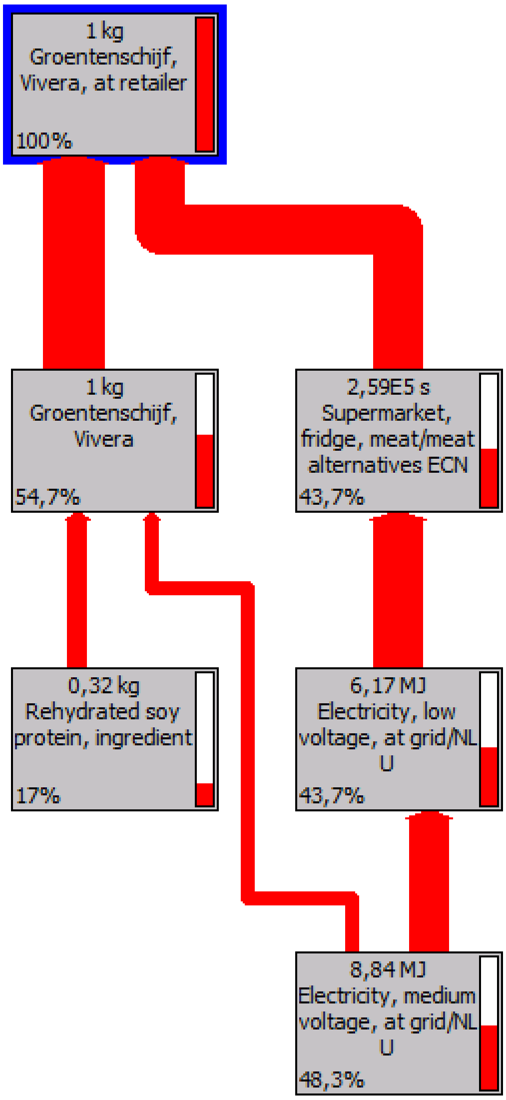


The results (see Figure 7) show that the greatest effect to nature and environment is as a result of the land transformation that takes place to grow soy and palm oil for the chicken feed.

4.2 Vegetarian Meat Alternatives

Figure 8 shows the relative contributions of the Vivera Groentenschijf (vegetable patty), on the basis of Human Health (DALY).

Figure 8 **Process network for 1 kg Vivera Groentenschijf at the point of retail, relative effects on Human Health (DALY)**

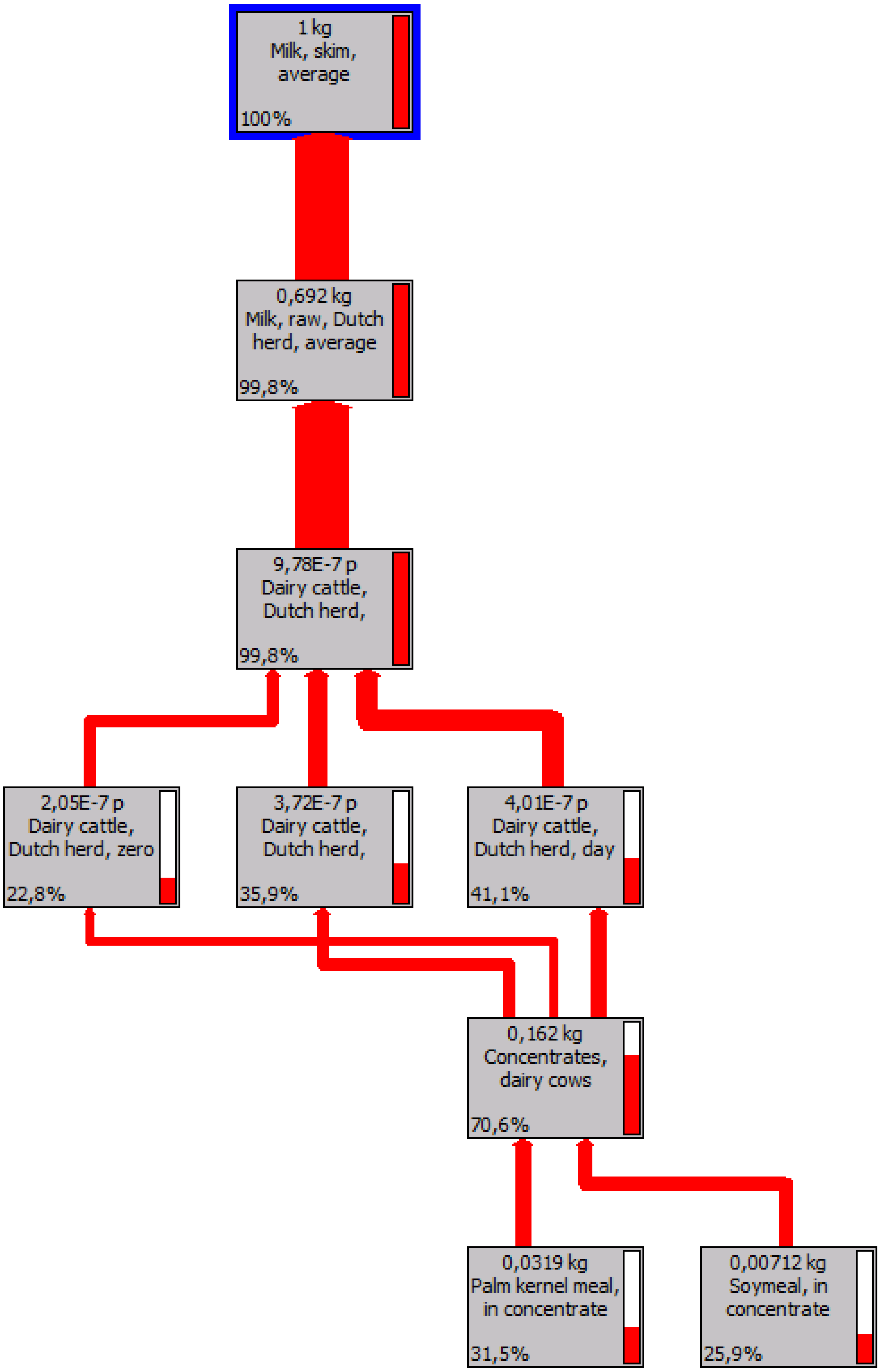


As shown in Figure 8, the effects on human health are dominated by the hard coal supply required to produce electricity for the production of the vegetable patty as well as the chilled storage of the patty in the supermarket. Electricity consumption tends to dominate the environmental impacts of the vegetarian products, as the other impacts are low in comparison.

4.3 Dairy Products and Alternatives

In Figure 9 the contribution of semi skim milk from average dairy cows to nature and environment is given.

Figure 9 **Process network for 1 kg semi skim milk from average dairy cows at the point of retail, relative effects on Nature and Environment (species.yr)**

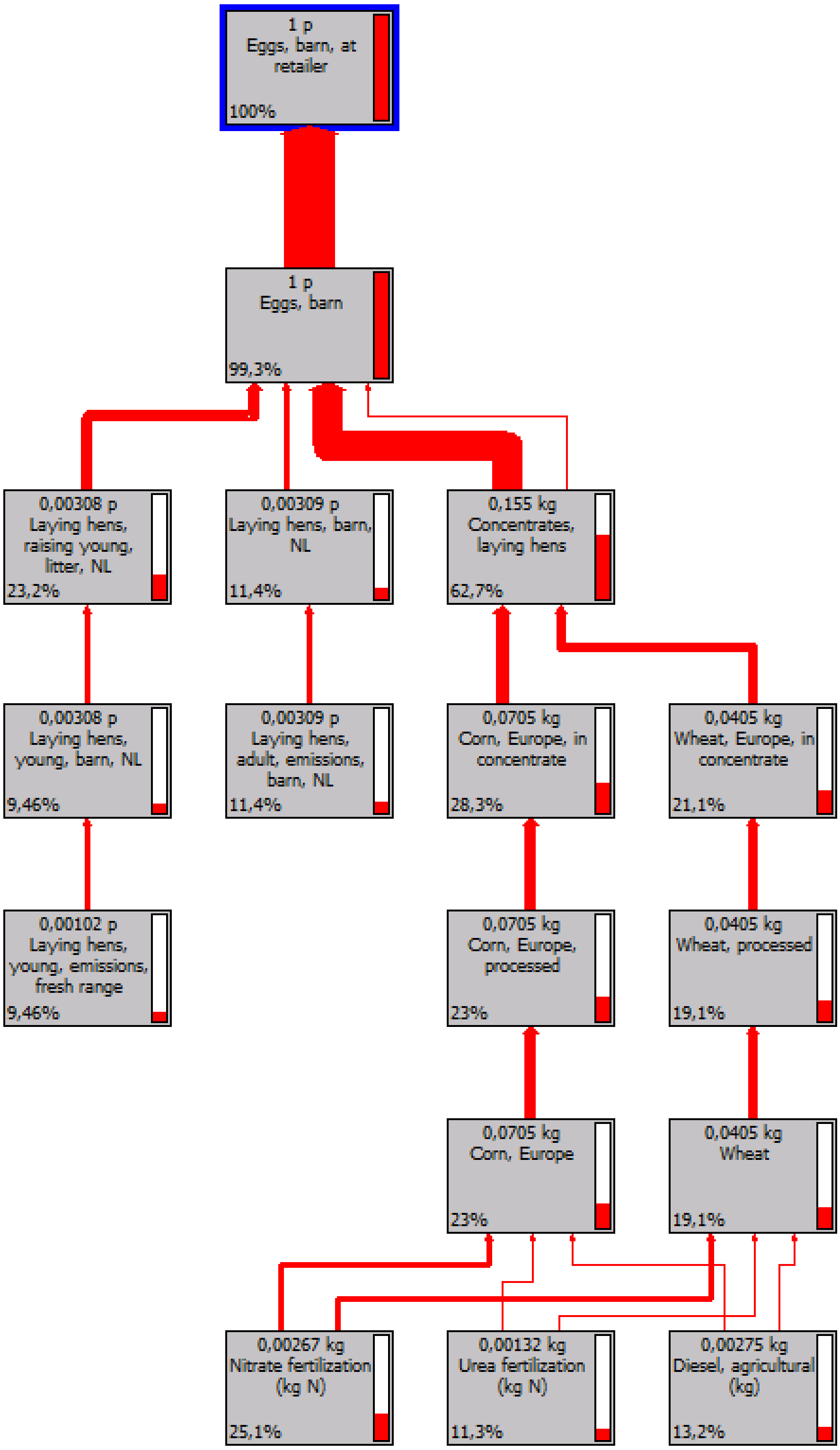


As shown in Figure 9, the dairy cow feed (concentrates) has the largest contribution to nature and environment. The reason for this large contribution is the impacts of land transformation from the palm oil and soy meal contained in the feed. Both of these crops are grown in regions where there is a great likelihood that the croplands were recently clear-cut tropical rainforest.

4.4 Eggs

Figure 10 shows the contribution of 1 kg barn (scharrel) egg to human health.

Figure 10 Process network for 1 barn (scharrel) egg at the point of retail, relative effects on Human Health (DALY)



Although the contributions to human health originate from several aspects of the lifecycle (direct emissions from laying hens), the greatest contribution to human health is from the production of feed. In particular, the cause of the higher contribution is as a result of the release of nitrogen from chemical fertilisers used to grow the crops contained in the feed.

5 Utilisation of Scores and Results

5.1 Comparison of Results with Literature

Climate change results (carbon footprints) are generally widely available for the various products. The results of this study have been compared with recent animal production life cycle studies. In particular, a recent study published by the Joint Research Council (JRC, 2010) analysed the life cycles for several animal agriculture products across all EU production countries. Additionally, Ponsioen et al. (2010) is used for in comparison of beef products, as regions outside of Europe are also covered. For Brazilian beef in particular, Cederberg (2011) was used in order to gain an insight into the contribution of land transformation to beef grazing. Finally, Broekema and Blonk (2009) provides results for various meat alternatives.

All results are presented per kg carcass weight. When the effects on climate change due to the land transformation are relatively high, they have been presented as a separate value between brackets.

Table 3 **Greenhouse gas emissions (kg CO_2 eq.) per 1 kg of carcass (before processing and packaging), product or otherwise specified unit, for a selection of products**

Products	Superwijzer (calculated LUC)	Broekema and Blonk, 2009	Cederberg, 2011	Ponsioen et al., 2010	JRC, 2010 (average scenario LUC)
Beef, AR	27.9			30.0	
Beef, BR	33.9 (+20.1)		28 (+44)*	30.0	48 (+40)
Beef, conventional NL	15.9			23.0	11.5 (+5.9)
Beef , DE	13.7				15.8 (+3.0)
Beef , IE	17.4			24.0	18.8 (-0.3)
Beef, nature NL	17.2			27.0	
Beef, PL	18.0				17.5 (+6.5)
Chicken, conventional, NL	2.7 (+1.5)				3.9 (+2.2)
Pork, conventional NL	5.6 (+0.9)				8.9 (+4.7)
Lamb, conventional, NL	11.3 (+1.2)				18.5 (+2.1)
Groentenschijf, Vivera	1.7	1.6			
Quorn	1.1	2.6			
Tofu (unsustainable soy)	1.3 (+1.1)	2.0			
Milk, cow, avg, NL (per kg raw)	1.24				0.9 (+0.5)
Egg, conventional, NL	3.4 (+0.8)				2.1 (+0.8)

* Average for Brazil.

As shown in Table 3, most of the results from *Superwijzer* are comparable to those from other sources, considering the likely differences in system boundary and other methodological choices. Emissions of land use change for Brazilian beef are an obvious example (see Annex C for more detail).

Of particular note, is conventional lamb, of which the score is almost half that of the CO_2 score in the JRC study. Once again, the differences have to do with the assumptions and methodological choices made as they relate to land use and land transformation.
Eggs have significantly higher greenhouse gas emissions in *Superwijzer* than the JRC study (2010), however. Half of the difference is explained by a higher contribution of LUC emissions; the other half appears to be due to a higher contribution of methane from the treatment of manure in the assessment in this study.

A significant difference exists (more than a factor 2) between *Superwijzer* and Broekema and Blonk (2009) for Quorn mince. This is related to the way in which the mycoprotein (the main ingredient in Quorn) is modelled. Broekema and Blonk (2009) modelled mycoprotein as a specific crop without indicating which crop was used. Mycoprotein in *Superwijzer* was modelled assuming that the crop is cane sugar, which is used 1:1 as a substrate for growing fungus. There is also a noted difference for tofu between these two sources. This is related to the way in which the soybeans used in making tofu is modelled, as soybeans grown in Brazil are modelled, taking into account land transformation (see Annex C).

5.2 Comparisons within Conventional Product Groups

5.2.1 Comparison of Conventional Meat Types

The differences in livestock management, feed, feed conversion and greenhouse gas production by ruminants are the main causes for the differences in environmental impact and land use. Human health impacts can occur through various means, including the pollution of local environments, the release of toxic compounds in the environment, and effects of climate change. The human health scores of different types of meat can differ, relative to the volatilisation of N-compounds from fertilisers, the amount of stable emissions occurring, and the emissions from transport. These processes emit compounds such as ammonia, nitrogen oxides, particulate matter and sulphur dioxide.

Table 4 Comparison of conventional meat types, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2)

Product	Nature and Environment		Climate Change		Human Health		Land Use	
	species.yr	% species.yr	kg CO_2	% kg CO_2	DALY	% DALY	m^2	%m^2
Beef, BR	1.10E-05	100%	87.11	100%	1.60E-04	100%	322.31	70%
Beef, AR	6.21E-06	56%	46.09	53%	9.99E-05	62%	459.63	100%
Veal, conventional	2.81E-06	26%	27.42	31%	5.43E-05	34%	28.64	6%
Beef, IE	1.82E-06	17%	25.65	29%	5.03E-05	31%	63.70	14%
Beef, NL conventional	1.77E-06	16%	23.90	27%	5.22E-05	33%	56.60	12%
Sheep, conventional, NL	1.72E-06	16%	15.06	17%	3.47E-05	22%	51.58	11%
Beef, PL	1.38E-06	13%	26.75	31%	4.98E-05	31%	24.13	5%
Beef, DE	1.34E-06	12%	20.35	23%	3.81E-05	24%	30.16	7%
Turkey, BR	1.17E-06	11%	8.85	10%	1.98E-05	12%	10.04	2%
Chicken, conventional, NL	1.06E-06	10%	5.96	7%	1.17E-05	7%	5.01	1%
Turkey, NL	1.08E-06	10%	9.34	11%	2.09E-05	13%	7.00	2%
Pork, conventional	9.61E-07	9%	9.01	10%	2.10E-05	13%	8.42	2%

Product	Nature and Environment		Climate Change		Human Health		Land Use	
	species.yr	% species.yr	kg CO_2	% kg CO_2	DALY	% DALY	m^2	%m^2
Rabbit, meat	8.64E-07	8%	20.14	23%	4.15E-05	26%	6.17	1%
Chicken, conventional, BR	7.96E-07	7%	5.75	7%	1.35E-05	8%	6.92	2%
Duck	8.08E-07	7%	6.11	7%	1.34E-05	8%	6.02	1%
Beef, cuts, dairy cows	5.07E-07	5%	12.62	14%	2.53E-05	16%	9.16	2%
Beef, mince, dairy cows	3.62E-07	3%	9.20	11%	1.84E-05	11%	6.50	1%
Chicken, corn, NL	1.23E-07	1%	4.27	5%	9.77E-06	6%	3.75	1%

Beef and Veal

Cattle from Brazil and Argentina have a major impact on biodiversity, because they contribute significantly to the deforestation of species-rich natural areas, including tropical rainforest and cerrado in the Amazon region. Deforestation also provides a large one-time emission of stored CO_2. In addition, ruminant animals produce large amounts of greenhouse gases (methane). Finally, the feed conversion ratio is the worst of all livestock species: on average 8.9 kg of feed is needed to produce 1 kg of beef. The cattle are managed extensively, which results in large land use requirements. The health effects on humans are also the highest, because of the greater amounts of nitrogen compounds excreted from the cattle.

There are notable differences between the cattle amongst European countries. Irish cattle and Dutch cattle score among the highest for biodiversity, as a result of having very large grazing areas of 54.5 m^2/kg meat, and 40.6 m^2/kg meat, respectively. German and Polish cattle, by contrast, receive much less pasture, 16.1 m^2/kg meat and 8.7 m^2/kg meat, respectively. However, in terms of climate change, Poland has the highest score. This is related to the population categorisation in the Polish National Inventory Report, which results in a slightly different population distribution and corresponding emissions, thus resulting in higher environmental scores. German cattle score low on all fronts as a result of both the low grazing and low emission profiles (as reported in the German National Inventory Report).

Mince and cut beef from the Netherlands has been separately modelled as this beef originates from dairy cattle. The environmental impact of this type of beef is low, as 94.5% of the environmental impacts are allocated to the production of milk.

Veal also has a relatively high impact on biodiversity since 15% of their feed consists of uncertified soy and palm (planted on deforested land). Due to their low food conversion ration, this translates to 0.9 kg of soy and 0.3 kg of palm oil per kg meat. The impact on human health is also quite high because the veal calf system also includes a portion of the dairy cow system, which is responsible for high ammonia and NO_x emissions.

Lamb

Like cattle, sheep are methane-producing ruminants, have a high feed conversion ratio, and are managed extensively, requiring a large share of land. Additionally, sheep are also fed about a 0.5 kg of soy per kg of meat produced. This explains the relatively high impact on biodiversity loss and greenhouse gases. Health effects are caused by the high levels of ammonia and NO_x volatilization in the pasture.

Chicken, Turkey and Swine

Although chickens and turkeys are about twice as efficient in converting feed to meat than pigs (1.7 versus 2.7 for pigs), their impact on biodiversity is higher because they consume 30% more soy per kilogram of meat produced (0.6 versus 0.45 kg). Ammonia emissions are the most dominating emissions for pig, chicken and turkey husbandry systems to human health. However, the effects on human health are higher for pigs than for chickens or turkeys, as a result of larger amounts of ammonia emissions (48.3 g/kg pig meat vs. 5.5 g/kg chicken meat or 3 g/kg turkey meat, respectively. The impact on the environment of corn fed chicken is the lowest of all meats, because the (uncertified) soy is replaced by grain.

Other Meats

While rabbit meat scores quite low for biodiversity and land use, it scores quite high for climate change. This high score can be explained by both the dinitrogen monoxide emissions emitted from the solid manure (N_2O has a greenhouse gas equivalent 298 times that of CO_2). Another major reason for the high climate change score has to do with the demand for rabbit meat and the length of time a given kg of meat will remain in the supermarket. Most types of meat remain in the chilled section of the supermarket for a few days. By comparison, rabbit meat is assumed to be stored in the freezer for an average of 15 days. This results in an electricity consumption that is ten times higher for rabbit meat than for pork, for example.

The reason for a high impact on human health is the large number of rabbits in the husbandry system required to produce a given quantity of meat. Rabbit carcasses only yield 50% quality meat cuts, whereas most animal types yield higher proportions of meat. Similarly, the mortality rates in rabbit production is much higher than for most animals (rabbits are more susceptible to disease), meaning that relatively more feed and emissions are released for a given kilogram of meat.

Ducks have relatively similar environmental scores as broiler chickens, due to the similarity of the species. In terms of biodiversity and climate change, the uncertified soy has the largest contribution. The human health contributions are mostly due to the high ammonia emissions that are formed in the indoor housing area.

5.2.2 Comparison of Meat Substitutes

There are currently several different types of meat substitutes on the Dutch market. Although they replace meat, meat substitutes can contain very different ingredients and require different processing, which leads to differences in environmental impacts. An overview of the environmental impacts can be seen in Table 5.

Table 5 **Comparison of meat substitutes, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2)**

Product	Nature and Environment		Climate Change		Human Health (DALY)		Land Use	
	species.yr	species.yr	kg CO_2	% kg CO_2	DALY	% DALY	m^2	% m^2
Tofu, uncertified soy	6.48E-07	100%	3.72	98%	1.04E-06	60%	2.1	71%
Tofu, uncertified organic	3.94E-07	61%	3.24	85%	1.04E-06	60%	2.49	85%
Valess	2.50E-07	39%	3.79	100%	1.74E-06	100%	2.94	100%
Groentenschijf, Vivera	5.77E-08	9%	2.95	78%	1.13E-06	65%	1.78	61%
Meatless	5.03E-08	8%	2.29	60%	1.44E-06	83%	2.71	92%
Falafel	4.59E-08	7%	2.51	66%	1.35E-06	78%	2.46	84%
Tofu, certified soy	3.91E-08	6%	2.54	67%	1.04E-06	60%	2.1	71%
Tofu, certified, organic	3.51E-08	5%	3.00	79%	1.18E-06	68%	1.95	66%
Quorn	2.77E-08	4%	2.4	63%	1.16E-06	67%	0.41	14%

Tofu
Four types of tofu have been modelled:
- tofu, uncertified: consists of soy from countries based on average import figures, including high biodiversity areas;
- tofu, certified: consists of soy that is certified and has thus not been grown on transformed land with high biodiversity, or soy from North America or Europe;
- tofu, uncertified organic: consists of organic soy from countries based on average import figures, including high biodiversity areas;
- tofu, certified organic: consists of organic soy from countries based on average import figures and that is certified and has thus not been grown on transformed land with high biodiversity, or soy from North America or Europe.

The origin, and thus the agricultural practices, of the soybeans has an enormous bearing on the environmental impact of soybeans (see Annex C for a detailed explanation). Soybeans that are produced in rainforest regions, Brazil in particular, are most likely to be grown on land that was deforested at some point in time. Due to the large extent of biodiversity in these regions as well as the role that rainforests play in CO_2 uptake, the consumption of soybeans from these regions has a huge environmental footprint. By contrast, certified soybeans or soybeans grown in North America and Europe do not have a large environment impact associated with them. Although croplands do account for a portion of occupied land that could otherwise be restored back to natural land, no or negligible land transformation takes place.

Heterogeneous Products
Heterogeneous meat substitutes have been categorised as having three major ingredients or more. These products include: the Vivera Groentenschijf, the Tivall Falafel and Quorn Mince.

The groentenschijf contains mostly rehydrated soy protein, followed by a large variety of vegetables and binders (starches and egg white). This product scores relative low in terms of biodiversity but has relatively high scores in the other three categories. This is because the electricity demand for the refrigeration in the supermarket greatly outweighs the production processes required to make the groentenschijf.

Falafel followed the same trend as the groentenschijf. As shown with the groentenschijf the impact on biodiversity is particularly low, however the scores for the other impact categories are high due to the refrigeration in the supermarket.

Quorn was also classified as a heterogeneous product, although the product is mostly composed of mycoprotein. Mycoprotein is produced from the mycelium of a species of the fungus *Fusarium* through a fermentation process (Steane, 2011). Due to limited ingredient information in Broekema and Blonk (2009), the base used for the fungus was not certain. Instead, cane sugar was assumed to be used as the major substrate for growing the mycoprotein, at a 1:1 ratio. The other ingredients present in Quorn are malted barley and dried egg white, although these ingredients do not contribute greatly to the overall environmental impact.

Other

Meatless has been categorized as other, as it tends not be consumed on its own, and is instead combined with meat to create sausages and other processed meats. Meatless acts as a filler that allows for the manufacture of products with lower fat and cholesterol contents.

As a result of its specific composition being a trade secret, Meatless was modelled as wheat, as per Blonk et al. (2008). For this reason it scored particularly low for biodiversity, however its scores for the other three categories, particularly land use (92%) were much higher. These higher scores can be explained by the impacts of electricity needed to refrigerate the product (along with the product that it is contained in) in the supermarket.

Valess has a much larger effects on human health than other meat substitutes. For Valess this larger effect on human health is due to the fact that 60% of Valess is skim milk, thus the environmental effects are more similar to dairy products than the meat substitutes. In particular, volatilised nitrogen from manure causes the high human health impacts.

5.2.3 Comparison of Conventional Cheese

Table 6 shows the results of conventional cheese for the various environmental impact categories.

Table 6 Comparison of conventional cheese, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2)

Product	Nature and Environment		Climate Change		Human Health (DALY)		Land Use	
	species. yr	% species. yr	kg CO_2	% kg CO_2	DALY	% DALY	m^2	%m^2
Mozzarella, buffalo	7.56E-07	100%	9.99	100%	5.21E-06	94%	8.87	100%
Cheese, cow, old, average	2.11E-07	28%	8.80	88%	4.67E-06	84%	4.76	54%
Cheese, goat, old	2.01E-07	27%	8.48	85%	5.57E-06	100%	6.91	78%
Cheese, cow, medium, average	2.01E-07	27%	8.02	80%	4.33E-06	78%	4.53	51%
Cheese, cow, young, average	1.94E-07	26%	7.57	76%	4.13E-06	74%	4.38	49%
Cheese, goat, medium	1.91E-07	25%	7.71	77%	5.18E-06	93%	6.58	74%
Mozzarella, cow	1.51E-07	20%	6.89	69%	3.51E-06	63%	3.41	38%

As shown in the above table (Table 6), buffalo mozzarella scores the worst in all but the health category, while cow mozzarella scores the best. There are several reasons for this difference. Firstly, buffalo are much larger animals than dairy cows so they require more feed. In addition, the buffalo feed has a far higher soy content than dairy cow feed (36% versus 12%). Another important contribution to the high scores is the fact that buffalo produce more manure and emissions, in addition to being less productive than dairy cows.

The differences between old, medium and young cow cheese are mainly due to the amount of milk required to produce the type of cheese. Old cheese requires more milk than medium cheese, and medium cheese requires more milk than young cheese, due to the higher milk solids content of older cheeses.

Despite significant larger land use, goat milk has a slightly lower impact then cow milk (species.yr and CO_2). This is due to dairy goats requiring less feed, as well as feed that does not contain soy. Impacts on human health are a bit higher because goat milk in the Netherlands is assumed to be transported farther than cow milk (50 km versus 35 km), since there are fewer goat milk farms than cow milk farms in the Netherlands and thus the milk needs to travel further on average.

5.2.4 Comparison of Conventional Milk

The results of the various milk types can be found in Table 7.

Table 7 Comparison of conventional milk, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2)

Product	Nature and Environment		Climate Change		Human Health (DALY)		Land Use	
	species. yr	% species.yr	kg CO_2	% kg CO_2	DALY	% DALY	m^2	$\%m^2$
Milk, soy, uncertified	1.54E-07	100%	0.89	68%	2.09E-07	22%	0.50	38%
Milk, cow, full cream, average	4.00E-08	26%	1.31	100%	7.77E-07	82%	0.90	69%
Milk, goat, full cream	3.82E-08	25%	1.25	95%	9.48E-07	100%	1.31	100%
Milk, cow, semi-skim, average	3.67E-08	24%	1.21	92%	7.17E-07	76%	0.83	63%
Milk, cow, buttermilk, average	3.00E-08	20%	1.04	79%	6.03E-07	64%	0.68	52%
Milk, cow, skim, average	3.00E-08	20%	1.01	77%	5.96E-07	63%	0.68	52%
Milk, soy, certified	9.31E-09	6%	0.61	46%	2.09E-07	22%	0.50	38%
Milk, soy, certified, organic	8.37E-09	5%	0.72	55%	2.70E-07	29%	0.46	35%
Milk, soy, uncertified, organic	8.37E-09	5%	0.72	55%	2.70E-07	29%	0.46	35%

As shown in Table 7, the three soy milk variants scored both the highest and lowest scores for biodiversity. This divergence can be directly linked to the assumptions made about the origins of the soy used in the milk. Soy milk made using uncertified (organic) soy has a far higher score than the soy milk using more certified sustainable soy. For a more complete explanation of the origins of soy, see Section 5.2.2. For the other impact categories, the three soy milk types have the lowest impacts. In particular, climate change impacts are lowest because of the fact that that the other milk types are produced by ruminants, which emit greenhouse gases.

Similarly to the cheese comparison, the whole cow's milk scored higher than the goat's milk for all categories. Most notably, this milk type had the highest score for all categories except biodiversity (this was awarded to soy milk made with uncertified soy). The scores for the other milk types decreased with decreased fat (and milk solids) content. This was previously explained in Section 5.2.3. Buttermilk has almost the same environment impact as skim milk because it is produced with skim milk.

5.3 Comparisons with Animal Husbandry Systems

5.3.1 Conventional versus Organic

In general, differences between organic and conventional are relatively small. Land use tends to be higher in terms of area occupied, but is often lower in terms of relative impacts. This is partly because land use is more extensive, but primarily due to zero contribution to land transformation. Other emissions with an impact on human health or ecosystems, including greenhouse gases (with exception of land use change emissions), follow this same trend.

5.3.2 Comparison of Conventional and Organic Meats

In general, all livestock species, except broiler chickens[3], come from the same stock and thus have the same genetic background. Therefore, in practice they have the same feed conversion ratio. But conventional livestock consume more (soy) concentrate, which has a larger impact on biodiversity. Differences in human health impacts are mainly caused by livestock management: most conventional livestock is kept indoors, resulting in a lower spread of pollutants such as nitrogen and particulate matter.

Table 8 shows the relative results of various conventional and organic meats.

Table 8 Comparison of conventional versus organic meats, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2). Brazilian beef is used as a benchmark and is not directly compared in this section

Product	Nature and Environment		Climate Change		Human Health (DALY)		Land Use	
	species.yr	% species.yr	kg CO_2	% kg CO_2	DALY	% DALY	m^2	$\%m^2$
Beef, BR	1.03E-05	100%	87.1	100%	3.78E-05	100%	322.3	100%
Veal, rosé, conventional	2.59E-06	25%	27.4	31%	1.57E-05	42%	28.6	9%
Sheep, conventional	1.60E-06	16%	15.1	17%	1.35E-05	36%	51.6	16%
Beef, NL, conventional	1.58E-06	15%	23.9	27%	1.86E-05	49%	56.6	18%
Beef, NL, organic	1.13E-06	11%	22.7	26%	2.17E-05	57%	47.3	15%
Chicken, NL, conventional	1.01E-06	10%	6.0	7%	3.39E-06	9%	5.0	2%
Pork, conventional	8.89E-07	9%	9.0	10%	8.33E-06	22%	8.4	3%
Sheep, organic	8.77E-07	9%	16.6	19%	2.43E-05	64%	50.27	16%
Veal, rosé, organic	7.37E-07	7%	15.8	18%	1.34E-05	35%	18.6	6%
Chicken, NL, organic	4.69E-07	5%	5.8	7%	6.58E-06	17%	5.2	2%
Pork, organic	4.33E-07	4%	10.3	12%	1.85E-05	49%	8.3	3%
Beef, NL, mince, dairy cows	2.88E-07	3%	9.2	11%	5.49E-06	15%	6.5	2%
Beef, NL, mince, dairy cows, organic	1.73E-07	2%	9.0	10%	5.64E-06	15%	8.3	3%

[3] Faster-growing breeds are used in conventional broiler chicken production, while slower-growing breeds are used in organic broiler chicken production.

Beef
Beef from conventionally-reared cattle receive feed containing more uncertified soy from Brazil than organically raised cattle (53% versus 25%, based on an assumption made from Badgley 2007) which accounts for a higher impact on biodiversity. Since the conventional and organic systems have been modelled in same manner and conventional cattle and organic cattle receive on average the same amount of pasture, the results for impact factors differ only slightly. The slight difference that does exist is due to the fact that some organic crops, namely soy, actually have higher yields in some areas than conventional crops.

Lamb
Although sheep eat large amounts of roughage, they also receive concentrate, which contains uncertified soy from deforested regions in Brazil. The difference between the conventional and organic lamb, is the percentage of soy originating from these regions as conventional soy is estimated to be 53% from Brazil, while organic soy is estimated to be 25% from Brazil. This has implications on biodiversity, as conventional lamb has score that is almost twice that of the organic lamb.

For climate change, the organic lamb has a slightly higher carbon footprint than conventional lamb, since manure is used instead of chemical fertilizer on the wheat straw, which has a higher amount of N. Organic lamb also has a higher human health impact than conventional lamb for the same reason.

Veal
The difference between conventional versus organic veal is again explained by the feed used. Conventional calves receive a feed that contains a higher percentage of soy from deforest land (53%), while organic calves receive feed containing a lower percentage of uncertified organic soy (25%). In addition, for every kg of conventional veal, 7.8 kg feed is required, versus 5.7 kg feed for organic veal, since conventional veal calves not receive the added roughage that the organic calves receive. The difference in human health effects is caused by the extra chemical fertilizer used for fertilizing the pastures.

The large difference in climate change impacts between the conventional and organic veal is due to a number of factors, including:
- More conventional calves are required for a given amount of conventional veal, than organic calves for organic veal. This has to do with the fact that the conventional veal calves are slaughtered at a younger age and thus has a lower slaughter weight than organic calves. This causes a greater amount of emissions, also when taking into account the extra weeks that the average organic veal calf is alive.
- A greater number of calves leads to a greater allocation of the dairy husbandry system, thus the conventional system has a higher level of emissions from dairy cows.
- More unsustainable soy is consumed by conventional calves than by organic calves.

Veal was modelled with data from WUR (2010). Throughout their lifetimes, calves receive artificial milk (25 kg powder[4]), corn (360 kg dw[2]) and calf feed (725 kg[2]) en very little roughage (70 kg dw[5]) compared to adult cattle. Since feed is one of the largest impacts, all unsustainable soy is weighted heavily in

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[4] WUR, 2010.

[5] Blonk, 2008.

terms of impacts on biodiversity. Calf concentrate contains 10% soy. When comparing 1 kg conventional feed with 1 kg organic feed, the biodiversity scores are 2.7E-7 en 9.5E-8, respectively.

Broiler Chickens

The scores for climate change and land use for conventional and organic chicken are practically the same; however there are differences in the scores for biodiversity and human health effects. This is related to the type of feed given to the chickens, as conventional chicken feed has a higher percentage of uncertified soy than organic chicken feed. In the case of effects on human health, organic chicken has an impact almost twice as large as the conventional chicken. The reason for this is due to the fact that organic chickens are often slower growing breeds and thus are only slaughtered after they reach twice the age of a the conventional chickens. Since the organic chickens live longer, they produce more manure and release more emissions.

Pigs

The scores for conventional versus organic pork are not consistent with one another. In terms of biodiversity, conventional pork has a score about twice as large as organic pork. The reason for the difference has to do with the high proportion of soy from deforested area in the pig feed. Conventional feed contains a higher proportion of this uncertified soy, which results in a higher impact on biodiversity. For climate change and land use, the differences between conventional and organic are smaller. In terms of impacts to climate change, organic pork has a slightly greater impact, mostly due to greater application of nitrogen on crops (sunflowers) than the conventional counterpart. Conventional pork has a slightly greater impact on land use, mostly due to the yields of conventional feed crops not necessarily being higher than organic crops (see Badgley et al., 2007). The difference in human health impacts between organic and conventional pork can be attributed to the greater release of nitrogen emissions from manure used on organic crops for organic pig feed than on synthetic fertilizers used on conventional crops for conventional pig feed.

5.3.3 Comparison of Dairy Products

There is a marked difference between conventional (grazing) and organic milk, as the results in Table 9 illustrate. Organic milk has a lower impact on biodiversity, but the impact on climate change and human health is about 26-27% higher. Organic dairy cows are less productive, producing 6,370 kg of raw milk per year, while conventional cows on average produce 8,050 kg per year. They also require more land, since grazing is obligatory during part of the year. This ‘inefficiency’ explains the differences on climate change and human health. However, since organic cows receive less concentrate in their feed, the impact on biodiversity is significantly lower. As milk is used as a raw material for all other dairy products, these differences also hold true for other dairy products such as cheese, yoghurt, etc., as seen in Table 10.

Table 9 **Comparison of dairy husbandry systems for milk products, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2)**

Product	Nature and Environment		Climate Change		Human Health (DALY)		Land Use	
	species/m^2	% species/m^2	kg CO_2	% kg CO_2	DALY	% DALY	m^2	%m^2
Milk, semi skim, average	4.63E-08	100%	1.21	84%	2.42E-06	82%	0.83	62%
Milk, semi skim, weidegang	4.54E-08	98%	1.20	83%	2.39E-06	81%	0.82	61%
Milk, semi skim, organic	3.92E-08	85%	1.45	100%	2.95E-06	100%	1.33	100%

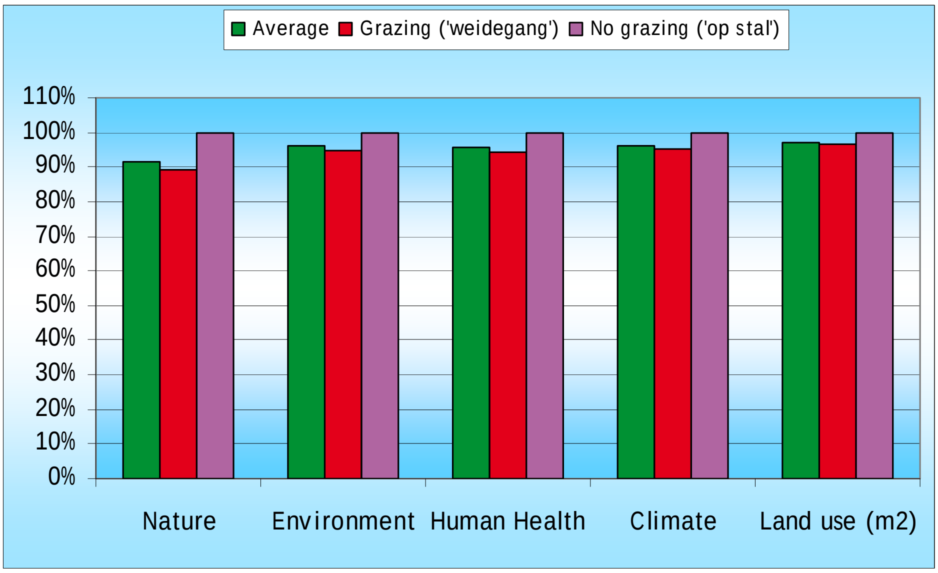
Table 10 **Comparison of dairy husbandry systems for cheeses, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2)**

Product	Nature and Environment		Climate Change		Human Health (DALY)		Land Use	
	species/yr	species.yr	kg CO_2	% kg CO_2	DALY	% DALY	m^2	%m^2
Cheese, medium, average	2.64E-07	100%	8.02	86%	1.56E-05	84%	4.53	62%
Cheese, medium, weidegang	2.59E-07	98%	7.98	86%	1.55E-05	84%	4.5	62%
Cheese, medium, organic	2.26E-07	85%	9.32	100%	1.85E-05	100%	7.3	100%

Recently, so-called *weidegang* milk, or pasture milk, is available as a product in stores. The cows that produced this milk have spent a minimum amount of time grazing in paddocks. The minimum requirement is 120 days per year, 6 hours per day. However, the majority of dairy farms in the Netherlands meet this criterion, regardless of their farm designation. This means that with current practice and information, one cannot really distinguish between the average milk and the specific *weidegang* milk in terms of environmental impacts.

In Figure 11, it is clear that there is some difference between grazing and zero grazing systems. The difference between the average and the grazing system is not significant, however.

Figure 11 Comparison in four categories for raw milk; average system, grazing, zero grazing



If all milk production that matches the criteria for *weidegang* milk were to be sold as such, the remainder could be assumed to be from zero grazing or very limited grazing systems. Thus, in future the two products may diverge to a greater extent, thus leading to different environmental profiles of the products as they are bought in the supermarket.

5.3.4 Comparison of Egg Types

There is wide range of different kinds of eggs available in supermarkets (see Table 1) however; there are groupings of egg types that have the same environmental impacts. This is due to similarities in the type and amounts of feed that the hens are receiving. Differences in environmental impact are mainly due to livestock management and feed composition. Most notably, livestock systems, which use non-certified soy have a relative high impact on biodiversity, while laying hens that eat corn and omega-3 feed (non-soy grains) have less impact as they rely mostly on temperate crops. The corn feed and omega-3 feed have biodiversity impacts that are 77% and 19%, respectively, of the impact of conventional layer hen feed.

Differences in climate change are due to the type and amount of feed. The eggs from hens with a greater degree of animal welfare (free range, Rondeel, etc.) tend to provide hens with more food. Although this is better for the animals, more feed translates to a higher environmental impact. As discussed above, different layer hen feed types have different ingredient compositions, meaning that some feed types (those containing soy from deforested regions, for example) have higher environmental impact. Another determining factor is the type of housing that the hens have. Battery and enriched caged hens lay eggs indoors, which is why these systems have a significant smaller impact on human health as less fine dust particles are emitted in the environment.

The omega-3 eggs have the lowest impact on biodiversity, the lowest impacts on climate change, yet they have the highest land use for all egg types. Considering the implications of land transformation on crops such as soy, this result seems counterintuitive. However, this land use has to do with *land occupation* and not *land transformation*. The crops used to produce omega-3 layer hen feed (wheat, oats, linseed, rapeseed, etc.) all have particularly low crop yields, meaning that more land is required to produce a given ton of crop.

Another outlying result is the particularly high effect on human health of the organic and omega-3 eggs. In the case of organic eggs, more nitrogen is applied to the crops in the form of manure than is applied in the form of chemical fertilizer. The nitrogen reacts and is volatilised, causing impacts on human health. The effect on human health for omega-3 eggs is not as extreme as for the organic eggs. Omega-3 feed is made primarily from wheat and oats, both of which use higher amounts of N-fertiliser than most crops.

As mentioned previously, feed amounts can vary between laying hen types. For example, battery layer hens have an adult feed conversion rate of 2.04, while feed conversion rates for barn (scharrel), free range and organic are 2.27, 2.32 and 2.43, respectively.

Although the organic layer hen feed does contain soy from deforested regions, it contains much less than the conventional soy (25% versus 53% unsustainable soy per kg soy in feed).

Table 11 **Comparison of eggs, per kg, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2).**

Product	Nature and Environment		Climate Change		Human Health (DALY)		Land Use	
	species/m^2	% species/m^2	kg CO_2	% kgCO_2	DALY	% DALY	m^2	%m^2
Eggs, free range (outdoors)	6.65E-07	100%	4.56	100%	2.48E-06	44%	5.57	81%
Eggs, 1 star (scharrel plus)	6.58E-07	99%	4.49	98%	2.45E-06	44%	5.31	77%
Eggs, grass	6.58E-07	99%	4.49	98%	2.45E-06	44%	5.31	77%
Eggs, barn (scharrel)	6.58E-07	99%	4.49	98%	2.45E-06	44%	5.31	77%
Eggs, enriched cage	6.00E-07	90%	4.26	93%	2.29E-06	41%	4.83	70%
Eggs, battery	6.00E-07	90%	4.26	93%	2.29E-06	41%	4.83	70%
Eggs, 60% corn	4.75E-07	71%	4.05	89%	2.29E-06	41%	4.71	69%
Eggs, Rondeel	3.32E-07	50%	3.86	85%	2.45E-06	44%	5.32	78%
Eggs, organic	3.08E-07	46%	4.43	97%	5.62E-06	100%	5.02	73%
Eggs, omega-3	1.71E-07	26%	3.82	84%	2.78E-06	49%	6.86	100%

5.4 Comparison of Most Common Meats and Meat Alternatives

In general, the impacts of the most commonly eaten meats (veal, beef, mince, chicken and swine) are much higher than the impacts of meat alternatives (see Table 12).

Table 12 **Comparison of the most common meat and meat alternatives, based on four environmental impact measures (species.yr, kg CO_2, DALY, m^2).**

Product	Nature and Environment		Climate Change		Human Health (DALY)		Land Use	
	species/yr	% species/yr	kg CO_2	% kg CO_2	DALY	% DALY	m^2	$\%m^2$
Veal, meat, rosé	2.81E-06	100%	27.42	100%	5.43E-05	100%	28.64	51%
Beef, NL conventional	1.77E-06	63%	23.90	87%	5.22E-05	96%	56.60	100%
Chicken, conventional, NL	1.06E-06	38%	5.96	22%	1.17E-05	22%	5.01	9%
Pork, conventional	9.61E-07	34%	9.01	33%	2.10E-05	39%	8.42	15%
Beef, mince, dairy cows	3.62E-07	13%	9.20	34%	1.84E-05	34%	6.50	11%
Chicken, corn, NL	1.23E-07	4%	4.27	16%	9.77E-06	18%	3.75	7%
Average common meats	**1.18E-06**	**42%**	**13.29**	**48%**	**2.79E-05**	**51%**	**18.15**	**32%**
Tofu, uncertified soy	6.48E-07	23%	3.72	14%	1.04E-06	2%	2.10	4%
Valess	2.80E-07	10%	3.79	14%	7.05E-06	13%	2.94	5%
Groentenschijf, Vivera	8.11E-08	3%	2.95	11%	5.26E-06	10%	1.78	3%
Meatless	6.84E-08	2%	2.29	8%	4.65E-06	9%	2.71	5%
Falafel	6.58E-08	2%	2.51	9%	4.86E-06	9%	2.46	4%
Tofu	5.92E-08	2%	2.54	9%	4.60E-06	8%	2.10	4%
Quorn	4.68E-08	2%	2.40	9%	4.53E-06	8%	0.41	1%
Tofu, certified soy	3.91E-08	1%	2.54	9%	1.04E-06	2%	2.10	4%
Tofu, uncertified, organic	3.51E-08	1%	3.00	11%	1.18E-06	2%	1.95	3%
Average meat alternatives	**1.75E-07**	**6%**	**2.95**	**11%**	**4.07E-06**	**7%**	**2.11**	**4%**

On average, meat alternatives have a seven times lower impact on biodiversity, about five times lower impact on climate change and human health, and require 8.5 times less land to produce. Although the nutritional value of the products may differ considerably, and meats like mince beef and (corn-fed) chicken have lower scores for certain impact categories than tofu and milk (Valess) based alternatives, these results illustrate that a diet shift from meat to meat alternatives will have a large positive impact on the environment.

5.5 Overall Conclusions

From these results it is clear that choosing products lower on the spectrum will lead to a significant impact on the environmental impact of an individual's dietary choices. A large scale shift from products with higher environmental impacts to products with lower environmental impacts could have enormous positive effects on the environment.

By making consumers aware of the large differences in environmental impact, both between different meat and meat alternative product groups, but also the difference within one product group. It is expected that raising awareness with consumers will give them a strong drive to choose the environmentally favourable alternatives.

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Annex A Environmental Impact Results per Product

Figure 12 Environmental impact results per kg product type

Product	Nature and Environment	Climate	Human Health	Land Use
	species.yr	kg CO_2	DALY	m^2
Beef				
Beef, Argentina	5.84E-06	46.1	3.48E-05	459.6
Beef, Brazil	1.03E-05	87.1	3.78E-05	322.3
Beef, Germany	1.18E-06	20.3	9.43E-06	30.2
Beef, Ireland	1.62E-06	25.6	1.41E-05	63.7
Beef, Poland	1.17E-06	26.7	1.21E-05	24.1
Beef, conventional, Netherlands	1.58E-06	23.9	1.86E-05	56.6
Beef, organic, Netherlands	1.13E-06	23.6	2.17E-05	56.7
Beef, nature, Netherlands	3.98E-07	25.7	8.53E-06	17.3
Beef, cuts, Netherlands (spent dairy cows)	4.07E-07	12.6	7.60E-06	9.2
Beef, mince, Netherlands (spent dairy cows)	2.88E-07	9.2	5.49E-06	6.5
Beef, mince, organic, Netherlands (spent dairy cows)	1.73E-07	9.0	5.64E-06	8.3
Pork				
Pork, conventional, Netherlands	8.89E-07	9.01	8.33E-06	8.42
Pork, organic, Netherlands	4.33E-07	10.26	1.85E-05	8.26
Pork, AH 1 star, Netherlands	8.89E-07	9.01	9.67E-06	8.42
Pork, AH 2 star, United Kingdom	8.90E-07	9.40	9.03E-06	8.45
Pork, Jumbo bewust, Netherlands	8.89E-07	9.01	9.67E-06	8.42
Pork, Milieukeur, Netherlands	8.89E-07	9.01	5.78E-06	8.42
Chicken				
Chicken, Brazil	7.50E-07	5.75	5.49E-06	6.92
Chicken, label rouge, France	4.57E-07	4.82	9.28E-06	5.15
Chicken, conventional, Netherlands	1.01E-06	5.96	3.39E-06	5.01
Chicken, organic, Netherlands	4.69E-07	5.78	6.58E-06	5.24
Chicken, corn, Netherlands	8.93E-08	4.27	3.79E-06	3.75
Chicken, scharrel, Netherlands	1.01E-06	6.40	3.86E-06	5.13
Chicken, volwaard, Netherlands	1.01E-06	6.26	3.77E-06	5.05
Other Poultry				
Duck, Netherlands	7.60E-07	6.11	4.88E-06	6.02
Turkey, Brazil	1.10E-06	8.85	7.41E-06	10.04
Turkey, Netherlands	1.01E-06	9.34	7.81E-06	7.00
Lamb				
Lamb, conventional	1.60E-06	15.1	1.35E-05	51.6
Lamb, organic	8.77E-07	16.6	2.43E-05	50.3
Veal				
Veal, rosé, conventional	2.59E-06	27.4	1.57E-05	28.6
Veal, rosé, organic	7.38E-07	15.8	1.35E-05	18.7
Veal, rosé, 1 star (van Drie)	2.59E-06	26.3	1.56E-05	29.2
Rabbit/Hare				
Rabbit, Netherlands	7.04E-07	20.14	1.33E-05	6.17
Hare, Argentina	3.48E-09	8.27	3.61E-06	0.15
Hare, Netherlands	3.11E-09	7.81	3.10E-06	0.14

Product	Nature and Environment	Climate	Human Health	Land Use
	species.yr	kg CO_2	DALY	m^2
Vegetarian Meat Alternatives				
Falafel, Tivall	4.59E-08	2.51	1.35E-06	2.46
Groentenschijf, Vivera	5.77E-08	2.95	1.13E-06	1.78
Meatless	5.03E-08	2.29	1.44E-06	2.71
Quorn, mince	2.77E-08	2.40	1.16E-06	0.41
Tofu, certified	3.91E-08	2.54	1.04E-06	2.10
Tofu, certified, organic	3.51E-08	3.00	1.18E-06	1.95
Tofu, uncertified	6.48E-07	3.72	1.04E-06	2.10
Tofu, uncertified, organic	3.94E-07	3.24	1.04E-06	2.49
Valess, schnitzel	2.50E-07	3.79	1.74E-06	2.94
Milk				
Milk, cow, whole milk, conventional	4.00E-08	1.31	7.77E-07	0.90
Milk, cow, whole milk, organic	3.03E-08	1.57	9.92E-07	1.45
Milk, cow, whole milk, pasture (weidegang)	3.91E-08	1.30	7.65E-07	0.89
Milk, cow, semi-skim, conventional	3.67E-08	1.21	7.17E-07	0.83
Milk, cow, semi-skim, organic	2.77E-08	1.45	9.14E-07	1.33
Milk, cow, semi-skim, pasture (weidegang)	3.58E-08	1.20	7.06E-07	0.82
Milk, cow, skim, conventional	3.00E-08	1.01	5.96E-07	0.68
Milk, cow, skim, organic	2.27E-08	1.20	7.57E-07	1.09
Milk, cow, skim, pasture (weidegang)	2.93E-08	1.00	5.87E-07	0.67
Milk, cow, buttermilk, conventional	3.00E-08	1.04	6.03E-07	0.68
Milk, cow, buttermilk, organic	2.27E-08	1.23	7.65E-07	1.09
Milk, cow, buttermilk, pasture	2.93E-08	1.03	5.94E-07	0.67
Milk, goat, whole milk, conventional	3.82E-08	1.25	9.48E-07	1.31
Milk, goat, whole milk, organic	2.94E-08	1.56	1.66E-06	1.67
Milk, soy, certified	9.31E-09	0.61	2.09E-07	0.50
Milk, soy, certified, organic	8.37E-09	0.72	2.70E-07	0.46
Milk, soy, uncertified	1.54E-07	0.89	2.09E-07	0.50
Milk, soy, uncertified, organic	9.35E-08	0.78	2.38E-07	0.59
Cheese				
Cheese, cow, old, conventional	2.11E-07	8.80	4.67E-06	4.76
Cheese, cow, old, organic	1.60E-07	10.17	5.80E-06	7.67
Cheese, cow, old, pasture	2.06E-07	8.75	4.61E-06	4.73
Cheese, cow, medium, conventional	2.01E-07	8.02	4.33E-06	4.53
Cheese, cow, medium, organic	1.52E-07	9.32	5.41E-06	7.30
Cheese, cow, medium, pasture	1.96E-07	7.98	4.27E-06	4.50
Cheese, cow, young, conventional	1.94E-07	7.57	4.13E-06	4.38
Cheese, cow, young, organic	1.47E-07	8.82	5.17E-06	7.05
Cheese, cow, young, pasture	1.89E-07	7.52	4.07E-06	4.34
Cheese, goat, old, conventional	2.01E-07	8.48	5.57E-06	6.91
Cheese, goat, old, organic	1.55E-07	10.13	9.32E-06	8.78
Cheese, goat, medium, conventional	1.91E-07	7.71	5.18E-06	6.58
Cheese, goat, medium, organic	1.48E-07	9.29	8.76E-06	8.35
Cheese, goat, young, conventional	1.85E-07	7.27	4.95E-06	6.35
Cheese, goat, young, organic	1.43E-07	8.79	8.41E-06	8.07
Cheese, buffalo, mozzarella, Italy	7.56E-07	9.99	5.21E-06	8.87
Cheese, cow, mozzarella	1.51E-07	6.89	3.51E-06	3.41
Yoghurt				
Yoghurt, cow, whole, conventional	4.02E-08	1.80	9.18E-07	0.91
Yoghurt, cow, whole, organic	3.04E-08	2.06	1.13E-06	1.46
Yoghurt, cow, whole, pasture	3.92E-08	1.79	9.06E-07	0.90

Product	Nature and Environment	Climate	Human Health	Land Use
	species.yr	kg CO_2	DALY	m^2
Yoghurt, cow, semi-skim, conventional	3.68E-08	1.66	8.46E-07	0.83
Yoghurt, cow, semi-skim, organic	2.79E-08	1.90	1.04E-06	1.34
Yoghurt, cow, semi-skim, pasture	3.60E-08	1.65	8.35E-07	0.83
Yoghurt, cow, skim, conventional	3.02E-08	1.38	7.01E-07	0.68
Yoghurt, cow, skim, organic	2.94E-08	1.37	6.92E-07	0.68
Yoghurt, cow, skim, pasture	2.28E-08	1.57	8.63E-07	1.10
Eggs				
Eggs, chicken, battery	6.00E-07	4.26	2.29E-06	4.83
Eggs, chicken, organic	3.08E-07	4.43	5.62E-06	5.02
Eggs, chicken, enriched cage	6.00E-07	4.26	2.29E-06	4.83
Eggs, chicken, barn (scharrel)	6.58E-07	4.49	2.45E-06	5.31
Eggs, chicken, 1 star (scharrel +)	6.58E-07	4.49	2.45E-06	5.31
Eggs, chicken, rondeel	3.32E-07	3.86	2.45E-06	5.32
Eggs, chicken, free range	6.65E-07	4.56	2.48E-06	5.57
Eggs, chicken, grass	6.58E-07	4.49	2.45E-06	5.31
Eggs, chicken, omega-3	1.71E-07	3.82	2.78E-06	6.86
Eggs, chicken, 60% corn	4.75E-07	4.05	2.29E-06	4.71

Annex B Detailed Explanation of Systems and Outcomes

Table 13 Explanation of the outcomes and the systems for each product type

Product	Remarks
Beef	Cattle emit a large amount of methane through enteric fermentation. They also require a large amount of space.
Beef, Argentina	These cattle are raised 100% on pasture and do not receive any feed beyond grazing. They do occupy a large amount of area compared to cattle in other countries.
Beef, Brazil	These cattle are raised 100% on pasture and do not receive any feed beyond grazing. They do occupy a large amount of area compared to cattle in other countries.
Beef, Germany	German cattle are raised partly indoors (in the winter) and partly outdoors. The modelled population has relatively many suckling cows, which have high levels of enteric fermentation.
Beef, Ireland	Irish cattle are raised partly indoors (in the winter) and partly outdoors. The modelled population has relatively many suckling cows, which have high levels of enteric fermentation. A large amount of live cattle are transported between the UK and Ireland by ferry.
Beef, Poland	The enteric fermentation from females has a large contribution to the environmental impacts as over half of the population consists of cows and heifers.
Beef, conventional, Netherlands	The conventional meat system in the Netherlands consists mostly of unwanted males from dairy system. In addition, a cattle are specifically bread for the beef industry.
Beef, organic, Netherlands	The conventional meat system in the Netherlands consists mostly of unwanted males from dairy system In addition, a cattle are specifically bread for the beef industry. No pesticides or artificial fertilizers are used in the organic feed
Beef, nature, Netherlands	Suckling cows and animals < 1 yr spend 3 winter months in stable with extra feed. The second year is spent entirely outdoors. While outdoors, only emissions of GHG are counted toward beef system. Of land use, 10% is counted toward beef system. Live weight at slaughter similar to conventional system.
Pork	Pig feed contains a large amount of soy, which is often grown in deforested tropical areas.
Pork, AH 1 star, Netherlands	The pigs in the AH 1 star system receive a bit more indoor space, mostly welfare improvements. Indoor space: 1 m^2
Pork, AH 2 star, United Kingdom	The pigs raised in UK, have access to the outdoors, which means that their ammonia and particulate emissions are low to non-existent, but they also utilise more pasture land. Indoor space: 1 m^2 Outdoor space: 4 m^2

Product	Remarks
Pork, conventional, Netherlands	The conventional pig in the Netherlands is Indoor space: 0.8 m^2
Pork, Jumbo bewust, Netherlands	The Jumbo bewust pigs receive a bit more indoor space per animal. Indoor space: 1 m^2
Pork, Milieukeur, Netherlands	Environmental controls are used to lower the NH_3 and PM emissions Indoor space: 0.7 m^2
Pork, organic, Netherlands	Organic crops require no pesticides or artificial fertilizers and a greater proportion is grown in temperate regions instead of tropical rainforest regions. Indoor space: 1.3 m^2
Chicken	CH_4 and N excretion in manure are quite high.
Chicken, Brazil	Meat is imported from Brazil.
Chicken, label rouge, France	The birds receive a large amount of space, both indoors and outdoors.
Chicken, conventional, Netherlands	A large proportion of the feed consists of soy, much of which comes from tropical regions, which are often deforested to produce cash crops.
Chicken, corn, Netherlands	Corn displaces soy in the feed, which has a much lower land use impact than soy.
Chicken, organic, Netherlands	no pesticides or artificial fertilizers used in feed
Chicken, scharrel, Netherlands	more space than conventional, improved welfare
Chicken, volwaard, Netherlands	more space than conventional, improved welfare
Other Poultry	Uncommon livestock so information was not available for breeder animals and thus were not included in the meat raising stage.
Duck, Netherlands	Emissions from manure are fairly low, which makes feed and meat refrigeration play a greater role.
Turkey, Brazil	Turkey feed contains soy and corn, which are grown on tropical land. The meat requires a longer refrigeration period.
Turkey, Netherlands	Turkey feed contains soy and corn, which are grown on tropical land.
Lamb	Sheep spend most of their time outdoors.
Lamb, conventional	Sheep receive sheep feed in addition to roughage. This feed mostly contains corn, along with soy
Lamb, organic	Organic crops for feed are grown without artificial fertilisers and pesticides. Common organic feed crops (corn, soy, etc.) are typically grown in temperate regions instead of tropical regions, which are often deforested to produce cash crops.
Veal	The impacts of the dairy life cycle behind the calves that are produced for the veal industry are relatively large.
Veal, EKO, Netherlands	Animals graze after 12 weeks of age from April to October. Through grazing and more indoor space they occupy more land. These calves are slaughtered at 11 months and thus require more feed. Since this is a small operation live animals are transported for shorter distances.
Veal, rosé, Netherlands	Animals are kept indoors. Calves are slaughtered at 8 months.

Product	Remarks
Veal, rosé 1 star, van Drie, Netherlands	Animals are kept indoors. Calves are slaughtered at 8 months but get more feed than their conventional counterparts. Shorter transport times are required for these calves.
Rabbit/Hare	Compared to other animal types, the carcass consists of little meat (~50%), meaning that the environmental impacts weigh heavier on the higher quality meat.
Hare, Argentina	Hunted from wild so emissions and food intake are part of natural ecosystems. The low impact of wild game is only the case if the hunting is conducted in a sustainable manner, i.e. does not disrupt the natural balance. Hare from Argentina requires more transportation from hunting area to NL
Hare, Netherlands	Hare are hunted from wild areas so emissions and food intake are part of natural ecosystems. The low impact of wild game is only the case if the hunting is conducted in a sustainable manner, i.e. does not disrupt the natural balance.
Rabbit, Netherlands	Rabbits are bred and raised in the same facility. Their feed contains mostly grains with small amounts of tropical oils (palm and soy).
Vegetarian Meat Alternatives	This category incorporates little to no animal products. The environmental impacts of these products are thus concentrated on the production of the crops
Falafel, Tivall, Israel	The Tivall falafels are made with chickpeas and soy oil. The production of soy, particularly soy grown in tropical regions, has high environmental impacts.
Groentenschijf, Vivera, Netherlands	The Vivera groentenschijf is predominated produced from vegetables; however it contains both soy oil and soy protein, as well as egg white.
Meatless, Netherlands	Meatless is made from lupine and wheat.
Quorn, United Kingdom	Quorn consists primarily of mycoprotein (a member of the fungi family) with flavour and egg white for consistency.
Tofu, certified, Netherlands	Conventional soybeans, which are grown in North America and Europe with artificial fertilizer and pesticides, are processed to make tofu. Soybean production in these regions is not linked to the deforestation of tropical regions.
Tofu, certified, organic, Netherlands	Organic tofu is produced with organic soybeans, which are grown without artificial fertilizer and pesticides. Certified soybeans are used, meaning that the soybeans are not linked to the deforestation of tropical regions.
Tofu, uncertified, Netherlands	Uncertified tofu is produced with uncertified soybeans. Unlike certified soybeans, 53% of soybeans imported in the Netherlands are assumed to have originated from regions where land has been deforested for agriculture.
Tofu, uncertified, organic, Netherlands	Organic tofu is produced with organic soybeans, which are grown without artificial fertilizer and pesticides. It is estimated that 25% of the organic soybeans imported into the Netherlands are grown in tropical regions where land transformation has taken place.

Product	Remarks
Milk	Milk is produced with dairy cows, which emit greater amounts of greenhouse gases both from enteric fermentation and in manure. All milk is from Dutch production systems, except for the buffalo milk for mozzarella which is produced in Italy.
Milk, cow, (whole, half, skim), conventional (average)	Milk is assumed to come from a mix of systems: zero grazing (21%), unlimited grazing (38%) and day grazing (41%). In addition to grass and roughage, dairy cows are also fed concentrates, which contain several ingredients, including those grow in tropical regions. The differences between whole, half and skim milk are related to the degree of milk dilution, with skim milk having the least environmental impact due to higher fraction of cream as a co-product that takes part of the environmental load.
Milk, cow, (whole, half, skim), organic	The main difference between organic and conventional milk is the proportion of cows grazing: zero grazing (0%), unlimited grazing (57%) and day grazing (43%). As such, organic dairy cows require less feed (and organic feed, using no artificial fertilizers and pesticides), on average smaller herds and more pasture land for grazing. The differences between whole, half and skim milk are related to the degree of milk dilution, with skim milk having the least environmental impact due to its lower dry solids content.
Milk, cow, (whole, half, skim), pasture	Pasture cows have similar grazing proportions as organic cows, but divided between two grazing patterns: unlimited grazing (50%) and day grazing (50%). The feed requirements however, are more similar to conventional milk as the cows receive conventional feed. The differences between whole, half and skim milk are related to the degree of milk dilution, with skim milk having the least environmental impact due to its lower dry solids content.
Milk, cow, buttermilk, conventional	Buttermilk is made with organic pasteurised milk in addition to salt. The milk is assumed to come from a mix of systems: zero grazing (21%), unlimited grazing (38%) and day grazing (41%). In addition to grass and roughage, dairy cows are also fed concentrates, which contain several ingredients, including those grow in tropical regions.
Milk, cow, buttermilk, organic	Organic buttermilk is made with organic pasteurised milk in addition to salt. The organic cows are grazed in the following ways: zero grazing (0%), unlimited grazing (57%) and day grazing (43%). As such, organic dairy cows require less feed (and organic feed, using no artificial fertilizers and pesticides), on average smaller herds and more pasture land for grazing.
Milk, cow, buttermilk, pasture	Pasture buttermilk is made with pasture-fed pasteurised milk in addition to salt. Pasture-fed cows are grazed as follows: unlimited grazing (50%) and day grazing (50%). The feed requirements however, are more similar to conventional milk as the cows receive conventional feed.
Milk, goat, conventional	Dairy goats are mostly kept indoors. Compared to cows, goats produce less milk (10%) and less emissions (7%).

Product	Remarks
Milk, goat, organic	Organic dairy goats have to access to both indoor and outdoor space. Organic dairy goats receive organic feed in addition to roughage.
Milk, soy, certified	Certified soymilk is made with soybeans that are grown in North America and Europe and thus do not propagate land transformation. These soybeans are cooked and processed into milk.
Milk, soy, certified, organic	Certified soymilk is made with soybeans that are grown in North America and Europe and thus do not propagate land transformation. Organic soybeans are grown without artificial fertilisers or pesticides.
Milk, soy, uncertified	Uncertified soymilk is said to contain 53% soybeans from Brazil, a region where a high proportion of deforestation takes place to make way for monoculture crops.
Milk, soy, uncertified, organic	Although this type of soymilk is produced with organic soy, 25% of the soybeans originate from Brazil, where deforestation of highly biodiverse land takes place.
Cheese	Several litres of milk are required to produce 1 kg of cheese
Cheese, cow, (young, medium, old), conventional	Conventional cheese is made with conventional milk, and involves an additional processing step which requires the use of additional energy. The milk is assumed to come from a mix of systems: zero grazing (21%), unlimited grazing (38%) and day grazing (41%). In addition to grass and roughage, dairy cows are also fed concentrates, which contain several ingredients, including those grow in tropical regions. The differences between young, medium and old cheese are related to the degree of milk dilution, with young cheese having the least environmental impact due to its lower dry solids content.
Cheese, cow, (young, medium, old), organic	Organic cheese is made with organic milk, and involves an additional processing step which requires the use of additional energy. The organic cows are grazed in the following ways: zero grazing (0%), unlimited grazing (57%) and day grazing (43%). As such, organic dairy cows require less feed (and organic feed, using no artificial fertilizers and pesticides), on average smaller herds and more pasture land for grazing. The differences between young, medium and old cheese are related to the degree of milk dilution, with young cheese having the least environmental impact due to its lower dry solids content.
Cheese, cow, (young, medium, old), pasture	Pasture cheese is made with pasture milk, and involves an additional processing step which requires the use of additional energy. Pasture-fed cows are grazed as follows: unlimited grazing (50%) and day grazing (50%). The feed requirements however, are more similar to conventional milk as the cows receive conventional feed. The differences between young, medium and old cheese are related to the degree of milk dilution, with young cheese having the least environmental impact due to its lower dry solids content.
Cheese, goat, conventional	Goat cheese is made with goat milk, and involves an additional processing step which requires the use of additional energy.

Product	Remarks
Cheese, goat, organic	Organic goat cheese is made with goat milk, and involves an additional processing step which requires the use of additional energy.
Cheese, cow, mozzarella	Cow mozzarella is made with conventional cow's milk, and involves an additional processing step which requires the addition of rennet (calf stomach enzymes). The milk is assumed to come from a mix of systems: zero grazing (21%), unlimited grazing (38%) and day grazing (41%). In addition to grass and roughage, dairy cows are also fed concentrates, which contain several ingredients, including those grow in tropical regions.
Cheese, buffalo, mozzarella, Italy	Buffalo mozzarella is made with buffalo milk and rennet and is produced in Italy. The buffalo are kept predominantly indoors or in intensive outdoor areas. Compared to dairy cows, buffalo require more feed and produce less milk, although their milk contains a higher concentration of dry solids content.
Valess, cow, conventional	Product is made from cow's milk/cheese, effects will be similar
Yoghurt	Yoghurt involves an additional processing step, requiring an input of energy.
Yoghurt, cow (whole, half, skim), conventional	Conventional yoghurt is made with conventional milk, and involves an additional processing step which requires the use of additional energy. The milk is assumed to come from a mix of systems: zero grazing (21%), unlimited grazing (38%) and day grazing (41%). In addition to grass and roughage, dairy cows are also fed concentrates, which contain several ingredients, including those grow in tropical regions. The differences between whole, half and skim milk are related to the degree of milk dilution, with skim milk having the least environmental impact due to its lower dry solids content.
Yoghurt, cow, (whole, half, skim), organic	Organic yoghurt is made with organic milk, and involves an additional processing step which requires the use of additional energy. The organic cows are grazed in the following ways: zero grazing (0%), unlimited grazing (57%) and day grazing (43%). As such, organic dairy cows require less feed (and organic feed, using no artificial fertilizers and pesticides), on average smaller herds and more pasture land for grazing. The differences between whole, half and skim milk are related to the degree of milk dilution, with skim milk having the least environmental impact due to its lower dry solids content.
Yoghurt, cow, (whole, half, skim), pasture	Pasture yoghurt is made with pasture milk, and involves an additional processing step which requires the use of additional energy. Pasture-fed cows are grazed as follows: unlimited grazing (50%) and day grazing (50%). The feed requirements however, are more similar to conventional milk as the cows receive conventional feed. The differences between whole, half and skim milk are related to the degree of milk dilution, with skim milk having the least environmental impact due to its lower dry solids content.

Product	Remarks
Eggs	Eggs are produced by layer hens. The chicken feed contains soy, most of which is grown in tropical areas which were deforested.
Eggs, chicken, 1 star (scharrel +)	These birds have more space than conventional hens. Indoor space: 8.5 hens/m^2
Eggs, chicken, 60% corn	Corn displaces some of the soy in the feed, which reduces the tropical land use impact of these eggs. Indoor space: 13hens/m^2
Eggs, chicken, barn	These birds have more space than conventional hens. Indoor space: 9 hens/m^2
Eggs, chicken, battery	The eggs from hens in enriched cages are very similar to battery eggs. Indoor space: 18 hens/m^2
Eggs, chicken, enriched cage	The eggs from hens in enriched cages are very similar to battery eggs. Indoor space: 13 hens/m^2
Eggs, chicken, free range	The hens have access to the outdoors and more indoor space. Indoor space: 9 hens/m^2. Outdoor space: 0.25 hens/m2
Eggs, chicken, grass	The hens have access to the outdoors and more indoor space. There must be a maximum of 7,5 hens/m^2 Indoor space: 7.5 hens/m^2 Outdoor space: 0.25 hens/m^2
Eggs, chicken, omega-3	Feed has different formulation than conventional feed, using crops that are grown in EU and North America, which have lower land use effects than crops grown in tropical areas where deforestations has taken place for cash crops Indoor space: 9 hens/m^2
Eggs, chicken, organic	No pesticides or artificial fertilizers used in feed Indoor space: 6.7 hens/m^2 Outdoor space: 18 hens/m^2
Eggs, chicken, rondeel	These birds have access to the outdoors and in general have more space. Indoor space: 6 hens/m^2 Outdoor space: 0.25 hens/m^2

Annex C Land Transformation

C.1 General Approach

For known ‘problem’ crops and/or countries, the trend in area harvested is assessed. Baseline for growth rates is the difference in area harvested between 1990 and 2009, based on FAO statistics. The annual growth rate is derived for this 20 year period. It should be noted that in practice growth rates are erratic from year to year, so another 20 year period may yield different annual growth rates.

The next step is to determine which fraction of the annual growth rates leads to transformation of natural land and, if larger than 0%, which types of natural land are transformed. Impact factors differ for different types of land; by far the highest factor available in the standard ReCiPe methodology is for transformation of tropical rain forest. Unfortunately, no other factors are available for tropical and subtropical areas, whereas large areas of land transformation in South America concerns savannah (cerrado) and temperate forests.

The 20 year period is chosen in line with IPCC practice for GHG emissions. Transformation impacts are also fully allocated to the subsequent 20 years of production.

In terms of soy used directly in food production, a somewhat different approach has been taken. Although there have been initiatives to reduce the consumption of soy from deforested croplands and companies producing meat substitutes claim to use soy from responsible sources (certified soybeans) in their products, uncertified soy was used as the default soy. However, in order to show the impacts of uncertified versus certified soy, three different types of tofu and three different types of soy milk where modelled: uncertified, certified and uncertified/organic. The ‘certified’ products are modelled with soybeans grown in North America or Europe, which are not responsible for the clear-cutting of rainforest.

C.2 Application to Products

C.2.1 Brazil

- Soy expansion rate ~3% annual; little direct deforestation but generally indicated as driver and move in within first 20 years. Expansion rate driven by animal feed.
- Sugar cane expansion rate ~3% annual; no direct deforestation, but indicated as driver. Expansion rate driven by biofuels. Main import of molasses into NL from India.
- Cassava, no expansion of area
- Cattle grassland, very high direct deforestation (70% of deforestation linked to cattle ranching) but ‘moving frontier’: more than 60% of deforested land ‘ultimately’ to agriculture (crops). Expansion rate in head of cattle 1.5% annual, expansion rate of area : see below
- Corn expansion rate ~1% annual, temperate zone, probably largely replacing existing grain production

There is discussion about whether the area of cattle ranching is increasing or decreasing. According to Grieg and Kessler, 2007, the area per head of cattle has remained constant over the last two decades, thus area should have expanded. Ponsioen et al. (2010) report a steady increase in yield per hectare and in fact a decrease in total area since 1990. This fact is corroborated by Cederberg et al (2011), who state that pasture productivity has on average increased from 43 kg carcass weight ha^{-1} yr^{-1} to 60 kg carcass weight ha^{-1} yr^{-1} over a decade (1997-2006). In the Legal Amazon Region the increase has been from 24 to 42 kg carcass weight ha^{-1} yr^{-1}. This leads to the conclusion that although direct deforestation for cattle ranching is huge, there is no net increase in cattle ranching area for the country in total. In other words, what is deforested on one side, is taken up by something else (soy, abandoned/ degraded land) on the other side. In calculating the contribution of land transformation, we follow the information in Cederberg et al. (2011) focussing on the Legal Amazon Region. There, 25% of Brazilian beef is produced and of the pasture land used, 25% is deforested (transformed) in the previous 20 years. Thus, a transformation factor of 6% is used (see Table 14).

Transformation for cattle in general concerns largely transitional and tropical rainforest and cerrado. Transformation for soy in general concerns primarily cerrado and transitional forest. However, in the final attribution, a significant fraction of (semi-)clearing of forest for cattle ranching is actually counted toward soy expansion (Grieg and Kessler, 2007). Therefore, land conversion for these two products is evaluated with roughly the same impact factor. We use a damage factor of 3E-5 (this is half of the factor for transformation from tropical rain forest, ReCiPe H) for soy. As transformation for cattle ranching is less invasive, the factor is set at 1E-5.

C.2.2 Soy, Other Countries in South America

- Soy expansion area 6% annual (ARG), 5% (PAR), 16% (URU).
- Argentina by far largest producer. Soy named as direct factor for deforestation.

Largely savannah (Chaco) and non tropical forest: damage factor 1.79E-6.

C.2.3 Cattle, Argentina

There has been a decrease in stocks and production quantity since 1990 (FAO stat). Grieg and Kessler (2007) report increases around 2000-2003, but this is not seen in the FAO statistics at all. These data have possible been adapted retrospectively, some earlier sources also report an increase based on FAO data, but later sources (2010) report more or less constant production.

Grieg and Kessler (2007) report relatively minor contribution to deforestation, even with their assumed increase. Here, we assume no deforestation to be attributed to cattle in Argentina.

C.2.4 Palm Oil

- Malaysia: annual expansion 4% since 1990;
- Indonesia: annual expansion 10% since 1990;
- Nigeria: annual expansion 1.5% since 1990;
- Average by total production is 6%.

Deforestation in general concerns tropical rainforest: damage factor 5.92E-5.

C.2.5 Citrus, Coconut

For coconut, the main producers are Indonesia, India, the Philippines, with an expansion rate of ~ 1% annually. For citrus, the main producer is Brazil, with decrease in area. The increases in area in many other countries (Mediterranean, Argentina), probably largely replace existing agriculture.

C.3 Biodiversity Factors

Based on this assessment, we apply the following factors to determine biodiversity loss associated with land transformation. For reference, the damage factor for land use is also given. Total effective biodiversity loss due to land use + land transformation is determined as:

1 hectare x DamageLU + 1 hectare x F x allocation x DamageLT/20

The allocation factors are derived from Grieg and Kessler (2007) for soy, palm oil and cattle. Part of the land transformation that is followed by cattle ranching is still allocated to soy production, because soy 'moves in' shortly after (within 20 year period). Allocation to sugar cane molasses is set to 0%. For coconut, an allocation of 50% of that of palm oil is assumed, as it is often produced in multi-cropping systems.

Table 14 Land transformation modelling for feed ingredients

Crop	Region	Annual growth rate	Fraction of land transformed in previous 20 years (F)	Allocation to natural land transformation	Damage LU	Damage LT
					Spec*yr/m^{2}a	Spec*yr/m^2
Soy	Brazil	3%	47%	78%	1.84E-8	3E-5
Soy	S America other	6%	70%	40%	1.84E-8	1.79E-6
Soy	Oher	0%		--	1.84E-8	--
Sugar cane	Al	1%-3%	50%	0%	1.84E-8	--
Cassava	Al	0%		--	1.84E-8	--
Cattle	Brazil	--	6%	65%	1.27E-8	1E-5
Cattle	Argentina	0%			1.27E-8	
Palm oil	Al	6%	70%	66%	1.52E-8	5.92E-5
Citrus	All	--		--	1.52E-8	--
Corn	Brazil	0%		--	1.84E-8	--
Coconut	All	1%	18%	33%	1.52E-8	5.92E-5

C.4 LUC Emissions

The total GHG emissions of land transformation are based on IPCC factors, calculated with an internal CE model (described in CE, 2009; see also CE, 2008). The effect allocated to one year of production is:

F x allocation x LUC_20_years/20

Table 15 Land transformation modelling for feed ingredients: GHG emissions

Crop	Region	LT	LUC over 20 years following transformation
			Ton CO_2 eq./ha
Soy	Brazil	Yes	516
Soy	S America other	Yes	154
Cattle	Brazil	Yes	516 (as soy)
Palm oil	All	Yes	540
Coconut	All	1%	As palm oil

For soy in Brazil, an average factor for tropical rainforest, tropical moist forest and Cerrado (savannah) is used. For Argentina (South America other), most soy expansion takes place in savannah area (Chaco) so that emission factor is used.

For cattle ranching in Brazil, no emission factor is available. We assume that the emissions of land clearing are the same as for soy. However, a thorough analysis of the interaction between cattle ranching and soy cultivation (expansion thereof) is required to establish true factors. Cederberg et al. (2011) present the first results of this, but unfortunately the role of soy is not made explicit in that article.

C.5 Soy, Mix of Origin for NL

Table 16 Soy, overall share origin based on imports of soy beans and soy cake for feed, into Netherlands

Country	kg	%
Brazil	3,644,200,346	53%
USA	931,001,818	13%
Argentina	2,087,205,760	30%
Paraguay	212,403,981	3%
Uraguay	39,740,320	1%