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Methodology used in FeedPrint: a tool quantifying greenhouse gas emissions of feed production and utilization

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Abstract
The methodology for calculating greenhouse gas emissions of the feed production chain is described in detail. Beside using existing guidelines, flexibility is realised by a systematic breakdown of the feed production chain into stages and a standardised method to calculate transport emissions, improved allocation is realized by detailed analysis of industrial processes. The calculation tool FeedPrint covers the complete Dutch Feed list, over 300 feed materials, sourced from countries all over the globe. Animal nutrition is incorporated in the tool to evaluate the ultimate effect of changing rations.

Keywords
Greenhouse gas emissions, feed production chain

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Preface

This report is one of the deliverables of the project “Carbon Footprint Animal Nutrition”. The project has been initiatied by the Product Board for Animal Feed and has been funded by:

- The Ministry of Economic Affairs, Agriculture and Innovation.
- Product Board for Animal feed
- Product Board for Arable products
- Product Board for Dairy products
- Product Board for Livestock and Meat
- Product Board for Poultry and Eggs
- Product Board for Margarine, Fats and Oils

Guidance of the project was done by a steering committee with representatives of all relevant stakeholders. All stakeholders provided technical support during the project. The contribution of all stakeholders has been very valuable.
The combination of material and immaterial support appeared to be very valuable.

The project can be considered as a successful public private cooperation to improve the sustainability of the livestock sector. The authors are very grateful for the ability to contribute to this joint initiative.

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Summary

Introduction

The contribution of the global livestock sector to emission of Greenhouse Gases is estimated to range from 12 to18%, through emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The awareness to tackle livestock-related GHG emissions across the world is increasing. Quantification of GHG emissions along various livestock production chains is the way to gain insight in the magnitude of emissions.
Cultivation, processing and transport of feed ingredients and the efficiency of feed utilization are key factors influencing the GHG emissions of livestock products. For this reason, the Dutch Product Board Animal Feed (PDV) initiated in 2009 the project "Carbon Footprint Animal Nutrition"(CFPAN) to develop an assessment tool. The objectives of the project and the tool were twofold:

1. to gain insight in the GHG emissions arising from the production and supply chain of animal feed and from feed utilization;
2. to use the resulting information as a starting point for identifying potential options to reduce these emissions.

Phase 1 of the project was an inventory of available knowledge and design of an architecture for the calculation tool. Based on the inventory, phase 2 of the project focussed at the elaboration of the methodology, collection of data and the development of a calculation tool.
This project will assess the current GHG emissions of the livestock production chain with the focus on the production of feed materials for all essential livestock sectors in the Netherlands. An attributional LCA is the most appropriate tool for such an analysis.
The GHG assessment of feed products with the calculation tool, named "FeedPrint" is primary meant to be used by organizations that formulate feed products (either in a factory or on the farm) to:

- allow internal assessment of the existing life cycle upstream GHG emissions of feed products;
- give support in the evaluation of alternative feed configurations, sourcing and manufacturing methods, raw material choices and supplier selection on the basis of upstream life cycle emissions of feed ingredients and feed formulation;
- create a benchmark for ongoing programs aimed at reducing GHG emissions;
- support reporting on corporate sustainability

This document describes the methodology used in the tool, based on Life Cycle Assessment (LCA) and is a main deliverable of phase 2 of the project "Carbon Footprint Animal Nutrition". The default data of all relevant processes have been collected and will be reported separately in a series of documentation reports and a summarising report.
Another main deliverable is the protocol, defining when stakeholders can use the default (secondary) data and when they should apply own, primary, data.

Measuring emissions of CO_2, CH_4 and N_2O in biological systems is complex, due to diffuse emission sources, low emission rates and a wide variation in conditions and hence in results. Therefore, GHG emissions from biological systems can be assessed by using simulation models with a solid empirical basis.
Communicating the results of simulation models can only be accepted when methods and data are fully transparent. Therefore in this report all methods and assumptions applied in the calculation of the GHG emissions are described or have been referred to international standards or are accepted methods based on peer reviewed publications in scientific literature.

Processes in feed production and utilization

In the first project phase it was decided that a proper assessment of the GHG emissions should contain feed production as well as feed utilisation. FeedPrint distinguishes realized GHG emissions of the upstream production of feed (raw) materials and in assessed downstream GHG emissions, caused by the utilization of feed by animals in commercial animal husbandry systems..

Methods of Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a method for an integrated analysis of environmental impacts along the life cycle of a product. The scope of this project is on the emissions of three greenhouse gases CO_2, CH_4 and N_2O. The ISO standards (14040/44) and the PAS 2050 of the British Standards Institute have been the basis of the methodology. Finally, all LCA methods have to be consistent with IPCC requirements on calculating GHG emissions on a national level.

FeedPrint follows a cradle-to-farm gate LCA approach, implying a functional unit for meat of 1 kg of live weight of a specific animal, for eggs of 1 kg of fresh eggs, and for milk 1 kg of FPCM leaving the farm-gate. For each animal product the most common Dutch farming system is assumed, implying an average housing type, average manure storage facilities etc. The allocation methodology applied in FeedPrint is based on the ISO rules (ISO 14044) and on the Dutch horticulture protocol. Economic allocation is the preferred method, FeedPrint provides opportunities to use allocation based on mass or gross energy.
The upstream boundaries of the assessment are at the level of inputs of fertilizers, fossil fuels, pesticides and agricultural machinery. Background data for the production and emissions of these inputs have been derived from databases. Downstream boundaries are at the farm gate.

Methods of GHG assessment
In most occasions, the 2006 IPCC Guidelines for the National Inventory Reports have been applied. In the case of methane emissions from enteric fermentation a Tier 3 method, used in the Dutch National Inventory Report has been applied.

Methods of data collection
General methodological starting points for collecting foreground and background data are: a) Consistent approach to ensure comparable calculation of GHG emissions for all feed materials. Consistency implies the use of the same data model for similar processes, completeness of data, applying the same criteria for data quality and a uniform approach for assessing missing data; b For each parameter an uncertainty estimate is determined to facilitate a Monte Carlo uncertainty assessment .c) Capital goods are included for transport means and agricultural equipment, but not for production plants, based on materiality of the contribution; and d) Other raw materials and consumables in processing are only included if previous LCAs proved that they have a material contribution.

Data collection was a two-step process. The first step was to collect data from the public domain (Scientific literature, FAOstat, Eurostat, etc.) including public research results from Blonk Consultants and WUR. The second step was to discuss the draft reports with experts from industry mainly from the feed industry stakeholders of CFPAN working group, or otherwise from authors identified from their publications on specific subjects.
Data quality has been assessed using the Pedigree Matrix, developed by Ecoinvent. Related to this, an uncertainty range and a distribution type have been attributed to all data.
Missing data have been assessed by using the MEXALCA method.

Crop production
In crop production the functional unit is defined as 1 kg of fresh product leaving the field, including the losses during harvesting and the losses at the first storage point (system boundary). The characteristic content of dry matter, carbon and gross energy are added to the product to able allocating emissions in later phases of the production chain. Inputs and activities are related to GHG emissions. Special attention is paid to the calculation of GHG emissions in grass production, mainly because grass is harvested multiple times per year. Emissions are calculated partly on a per cut basis and partly on an annual basis.
In GHG emissions assessment, the carbon of plant and animal materials is considered to be part of the short carbon cycle . So, carbon in crops, animal products and manure is not considered as a carbon sink, nor as an carbon emission source. An important exception is carbon sequestered in soil organic matter is considered as a carbon sink. From this perspective land use (grassland, arable land and permanent crops) and land use change is taken into account, because of the change on carbon stocks due to cultivation practices.
On the basis of the complexity of direct and indirect land use change, LUC assessment of single crop is useless A simple and robust method has been developed. based on the idea that human consumption is the driver and that all agricultural production systems are connected. This is especially the case for market oriented agriculture and to a lesser extent to non-commercial agriculture. From this point of view all land use change emissions (non-agricultural land converting to agricultural land) should be related to the agricultural land itself. This results in a calculated average emission of land use change for every hectare in agricultural use on the globe. For a product based land use change emission, the emission per hectare has to be divided by the yield per hectare. The method is not a cross-sectorial analytical tool for analysing drivers of land use change. It in fact only accounts for the

emissions caused by the shift from non-agricultural land to agricultural land and does not account for land use change within agricultural land.
For land use emissions, a simple carbon balance model has been used, with the current use as the reference level.

Industrial processing
The reference unit in the industrial processing is directly related to the output as described in the crop cultivation: 1000 kg input of crop material. This reference unit is defined as it is directly prior to processing. Thus, all energy and auxiliary material inputs are related to the 1000 kg of crop material input, on an ‘as is’ basis. The energy inputs were either expressed as kWh/1000 kg input for electricity or MJ/1000 kg for fuels (diesel, natural gas, etc.). All auxiliary materials were reported in kg material/1000 kg input.
Capital goods and use of consumables in processing as well as activities that are not directly related to the processing, are not taken into account.
In industrial processing, three different situations have been distinguished:

1. **Overall input/output based allocation.** The production system that produces the co-products is strongly interrelated, thus always produces the same type of outputs while the processing steps after the separation step have relatively small inputs compared to the joint inputs before separation.
2. **Unit process separation with allocation at each process step.** The production system produces several co-products equally important for the total revenue without a distinct main product in both intermediate and further processed form.
3. **By-product treated as residue.** The production system has a distinct main product(group) and produces by-products both in its low value intermediate (often wet) form optionally further processed into (dry) products.

The second situation is especially important in the case of wet co products.

Prices
For imported products from countries overseas, the use of export prices (Free On Board) is preferred above CIF (Cost, Insurance and Freight) prices. If export prices are not available, import prices must be used that carry the least transport costs.
For many products, processing is done in more than one country. If available, country specific prices will be used to calculate off factory-prices. If country specific prices are not available, the ratio of prices in another country will be used as starting point to calculate off factory prices.
Conversion from one to another currency is done by taking the annually averaged exchange rate. For each currency the exchange rate at the first day of the month is used to calculate an average exchange rate for each year. Whenever possible, average prices over the most recent five year period will be used.

Animal nutrition and farm
The feed ration is composed of the various feed (raw) materials and depends on the animal type and the production goal. The nutritional quality of the feed materials is based on the default values of the Dutch feed list of the “Centraal Veevoeder Bureau” (CVB-list). An average nutritional quality of the feed is calculated as a weighted average of all feed components.
The nutritional models of the animals simulate feed intake and calculate growth rates of young animals and production rates of milk and eggs for dairy cows and laying hens, respectively.

Manure “production”, housing, storage and emissions
Organic matter in animal manure is calculated from feed intake and digestibility of organic matter, the excretion of the nutrients N and P is based on the difference between intake via feed and retention in growing tissue, milk and eggs. The partitioning of N over organic and mineral nitrogen in excreta is based on the digestibility of the crude protein in the feed. The mineral N is excreted as Total Ammonia Nitrogen (TAN), based on digestibility of crude protein. Ammonia emissions from manure storage are based on the TAN excretion, emissions of nitrous oxide are based on 2006 IPCC Guidelines. Methane emissions from manure storage are based on emission factors as used in the National Inventory Report.

Transport
Emissions related to transport are based on the transport distance and the type of transport. Transport distances on land are calculated using mid points of countries or of production regions within a country and the main sea port. Transport overseas is based on the transport distance from the main sea port in a country to the port of Rotterdam. Emissions of transport modalities are based on Ecoinvent data.

Examples
The novelties in the FeedPrint methodology have been demonstrated in the last chapter, showing the advantages of a) the systematic breakdown of the production chain into stages; b) the improved allocation method by the breakdown of processing and c) the standardisation of the transport calculations. Differences in GHG emissions between products can now clearly be related to their routing through the feed production chain. Additional calculation examples show the importance of the choice of the allocation method (economic, gross energy or mass) and of the selection of the land use change methodology. Finally, a Monte Carlo simulation shows thee effects of data uncertainty.

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1 Introduction

1.1 Livestock production and greenhouse gas emissions

Livestock production is recognized to contribute significantly to emission of greenhouse gases (GHGs), mainly through emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The contribution of the global livestock sector to emission of GHGs is estimated to range from 12 to18% (Steinfeld et al.., 2006; PBL, 2009). Carbon dioxide is mainly released from combustion of fossil fuels to power machinery, from burning of biomass, and from microbial decay related to, for example, changes in land use or in crop management. On the contrary carbon dioxide can be sequestered by, for example, transforming arable land into permanent grassland or by adaptations in soil management in arable farming. Methane is produced when organic matter decomposes in oxygen-deprived conditions, i.e. during enteric fermentation in ruminants and storage of manure or organic waste material of processing industry. Nitrous oxide is released during microbial transformation of nitrogen in the soil or in manure (i.e. nitrification of NH_4^+ into NO_3^-, and incomplete denitrification of NO_3^- into N_2). Policy makers, scientists and businesses across the world are increasingly aware of the need to tackle livestock-related GHG emissions. Quantification of GHG emissions along the various livestock production chains is the way to gain insight in the magnitude of emissions. Part of the quantification is summarizing emissions of the main GHGs in terms of CO_2-equivalents (i.e., 1 for 1 kg of CO_2, 25 for 1 kg of CH_4 and 298 for 1 kg of N_2O), and relates this global warming potential to the reference unit (RU) of a production chain. A RU represents a normalized quantity of a production system in relation to the anticipated use of that quantity, such as one kg fat-protein-corrected milk (FPCM) of one kg of live weight.

GHG emissions assessment of livestock products showed that cultivation, processing and transport of feed ingredients, and the efficiency of feed utilization are key factors influencing the GHG emissions of livestock products (De Vries and de Boer, 2010). This stimulated interest of various stakeholders in the livestock sector to develop a tool that enables quantification of the GHG emissions of production of feed ingredients (cultivation, processing and transport) and of their utilization by animals. The Dutch Product Board Animal Feed (PDV) initiated already in 2009 a project to develop such an assessment tool (see section 1.2), which can be utilized by national and international companies and organisations. The development of a tool to quantify the GHG emissions of livestock products implied some specific challenges

- Compared to industrial processes, non-CO_2 emissions, and especially N_2O and CH_4, are highly important in the livestock production chain. The non-CO_2 emissions are modelled on the basis of N and C flows in agricultural systems. Defining accurate and practicable models to predict non-CO_2 emissions from livestock production was a major challenge of this project.
- Livestock consume a great variety of raw materials from agriculture and co-products from processing industry. Hence, assessing the GHG emissions of livestock products implies knowledge about a large number of industrial processes of food products.
- Feed ingredients of Dutch livestock products originate from all over the world. Accurate prediction of GHG emissions of all Dutch feed ingredients requires large amounts of data of cultivation, processing and transport of feed globally. In case of unavailability of data, generic methods have to be developed to consistently estimate GHG emissions of global feed ingredients.
- Land use (changes in management) and land use change (e.g. deforestation), also referred to as LULUC contributes to GHG emissions of livestock products. At this moment, no generally accepted and harmonized method is available to quantify these emissions.

The PDV wanted to develop a dynamic and interactive tool for assessing GHG emissions of animal feed, and make this available to stakeholders in the animal feed sector. The objectives of this tool are twofold: first, to gain insight in the GHG emissions arising from the production and supply chain of animal feed and from feed utilization; and second, to use the resulting information as a starting point for identifying potential options to reduce these emissions. The tool is not intended for use in the labelling of products. The development of the tool has been supported by the ministry of Economic Affairs, Agriculture and Innovation. The central government made an agreement with the agricultural sector (Land en Tuinbouw Organisatie, LTO) and with the feed sector (Nederlandse Vereniging van Diervoederproducenten, Nevedi) with the name “Schone en zuinige agrosectoren”. This is part of a national program on reduction of GHG emissions.

This document, that contains a description of the methodology used in this tool, is one of the deliverables of phase 2 of the project. phase 1 concerned an inventory of available knowledge and design of an architecture – a ‘blueprint’ – for the calculation tool (Blonk et al., 2010).

At the end of phase 1 the following recommendations regarding a strategy for phase 2 were defined.

a) The life cycle assessment (LCA) methodology is available to develop a GHG assessment calculation tool for animal nutrition. However, four issues need further (international) discussion to gain wider support: a) land use and land use change; b) economic allocation; c) system boundaries; and d) improvement options. Phase 2 needs to focus on resolving these issues;
b) Further study on the GHG emissions of feed additives is required. Data need to be collected on the effect of adding enzymes, mineral additives and synthetic amino acids on animal production, as well as on the GHG emissions of the production of these additives as such;
c) Many background data need to come from crop growers and suppliers of feed materials; so, a great effort is needed to develop a robust database that is aimed to be made publicly available. It should be developed in cooperation with suppliers of feed materials;
d) Calculation models and background data are needed to describe the conversion of feed into animal products, CH_4 emissions from enteric fermentation and from manure in diverse storage facilities, and N_2O emissions from inside and outside storage of manure. Descriptive models will be sufficient for the first version of the GHG emissions assessment tool. In later versions, mechanistic models, if available, should be included;
e) Development of the tool in phase 2 should involve several coordinated parallel activities on methodology and database development and the development of the software for the GHG emissions assessment calculation tool;

Methodology and database development should involve preferably a consortium of international organizations to engender broad support for the approach.

1.2 The goal of the project

On the basis of these recommendations, the overall goal of phase 2 of the project “Carbon Footprint Animal Nutrition” is twofold:

a) To elaborate the recommendations a, b, c and d concerning methodology, data collection etc. as mentioned in chapter1.1.
b) To establish a GHG emissions calculation tool to calculate and evaluate the greenhouse gas emissions of their (feed) products. This tool can be used by the companies and organizations within the scope of the PDV, and other national and international parties concerned to which the model will be made available.

The operational goals of the project were:

a) To provide the methodology, protocols, formats and (default) data for building an operational calculation tool.
b) To develop the operational calculation tool as a basic program with interface, that can be used as a standalone model. Possibilities to integrate the tool by stakeholders in their own information infrastructure will be explored; the opportunities for such integrations will be taken into account as a condition in the development of the tool.
c) To test the calculation tool on correctness of content (does it properly calculate the GHGs on the basis of the provided input as mentioned under a).

The calculation tool is named “**FeedPrint**” and is a central element in the project. FeedPrint should help stakeholders along the chain to gain insight in and to explore and identify mitigation options. The reporting of the project, therefore, is constructed to support the use of FeedPrint and understanding final FeedPrint results (Table 1). For reporting, two goals have been considered: (1) the optimal use of FeedPrint, focusing on practical help when working with the tool (described in a user guide) and (2) the optimal impact of FeedPrint results. To fully understand and accept results generated by FeedPrint, we provide a set of rules in a protocol, the methodology behind these rules and we report on default data used. Additional to the protocol, methodology and default data reports, scientific publications and documentation reports will be written. The first one will present on new findings on the methodology and the latter will contain detailed documentation of all collected data including the reasoning for the choice of the default data.

Table 1. An overview of the reporting structure to support the use of FeedPrint.

Goal	Overview	➔ ➔	Detail
Optimal use of FeedPrint	User guide		
Optimal impact of FeedPrint results	Protocol	Methodology report	Documentation reports on data
		Scientific publications	

This report describes the methodology used in FeedPrint, including sensitivity and uncertainty analysis.

1.3 The need for transparencyal

Calculating GHG emissions of industrial processes, energy production or transport is relatively straightforward. Inputs and outputs of the technical processes can be measured relatively simple and the level of uncertainty is limited. The most important GHG from industrial processes, energy production or transport is CO_2. In agricultural (biological) systems, emissions of CH_4 and N_2O are very important (IPCC, 2007). Emissions of CO_2 in agriculture are related to the use of fossil fuels and to changes in carbon stocks in land. The first is similar to CO_2 emission from industrial processes, the latter is a biological process. Measuring emissions of CO_2, CH_4 and N_2O in biological systems is often complex. GHG emissions in biological systems are often very diffuse, which means that they occur over a large area or a large unit of time, leading to often very low emission rates. Another characteristic of biological systems is the wide variation, due to variation in conditions such as temperature, moisture, soil structure, availability of water, oxygen and nutrients, microbial variation and genetic properties of animals. E.g. N_2O emissions from agricultural soils are in the range of 5–10 kg N_2O per hectare per year on intensive dairy farms, which is about 1.5–3 milligrams of N_2O per m^2 per day. Emissions factors used for calculating N_2O emissions have a variation coefficient of 50% and sometimes more (Velthof et al.., 1997, 2003; IPCC, 2006). This means that measuring actual emissions in biological systems is only useful with very accurate equipment and many detailed measurements, which is only feasible under experimental conditions. As a consequence, GHG emissions from biological systems can be calculated only by using simulation models, with a solid empirical basis. Models require calculation rules and input data, but are not able to cope with all variation in biological systems. Even the mechanistic models, that simulate underlying biological processes, are not able to deal with all existing variation. All models are a simplification of reality and require a set of assumptions in the situation where model parameters are not known or where input data cannot be obtained.

Model results depend on model assumptions, and the quality of parameters and input data used. To understand and trust final results of a model simulation, one needs to know model assumptions, understand calculation rules, and have insight into data quality. Generation of trustworthy model results requires transparency, or in other words, users of the model and of model results should have access to calculation rules, assumptions and input data to be able to check and compare.

In this report we will report all methods and assumptions applied in the calculation of the GHG emissions of feed and of feed utilization by animals. This is partly done by detailed descriptions of the methods and partly by referring to international standards or accepted methods based on peer reviewed publications in scientific literature.

1.4 Uniformity

Many studies have been performed to calculate GHG emissions from livestock systems. The IPCC uses a sectorial approach for agriculture (IPCC, 2007), using their own guidelines for emissions (IPCC, 2006). Appendix 1 countries have to apply the IPCC 2006 Guidelines as well, but are allowed to use emission calculations at a higher (Tier 3) level. In research, many studies have been performed at the farm level (e.g. Schils et al.., 2007b; Cederberg et al.., 2009; Basset-Mens et al.., 2009; Thomassen et al.., 2008) or at the sector level (Blonk et al., 2008; Capper et al.., 2009; Sevenster and

De Jong, 2008) or at regional level (Herrero et al., 2008) and at the global level (Steinfeld et al., 2006, Gerner et al.., 2010).
Studies at the level of individual farms allow the use of primary data on feed production, the use of inputs and the application of site specific calculation rules for GHG emissions and allocation rules for partitioning emissions. These studies are very useful in providing insight at the farm level, but the comparison of results is often complex (De Vries and De Boer, 2010). This also holds at the regional or global level. E.g. emission figures of IPCC (2007) and of Steinfeld et al. (2006) and Gerber et al.. (2010) are different, due to the differences in scope of these studies. Studies on aspects of GHG emissions, like CH_4 are complicated to compare due to the differences in models and energy evaluation systems for feed used (Bannink et al.., 2010; Herrero et al.. 2008; IPCC, 2006).
Different choices in allocation factors and rules also contributes to incomparability of final results. The mandatory allocation to co-products (often used for feed) in the case of biofuels in Europe is based on the gross energy content (EU, 2009), whereas allocation on the basis of economic value is the preferred option in feed industry (Blonk and Ponsioen, 2010). Different allocation approaches at the farm gate have been found as well. Gerber et al.. (2010) are allocating on the basis of protein production in meat and milk, whereas IDF (2010) recommends allocation on the basis of energy requirements for milk and meat production. In most livestock studies, however, economic allocation has been applied for meat and milk (De Boer and De Vries, 2010).
Although variation is present, the significant contribution of livestock to global GHG emissions is obvious. Intensive livestock production systems (dairy, pork and poultry) in industrialised countries have a relatively low GHG emissions per kg of product and mitigation options are often realised by small steps (e.g. Vellinga et al., 2011). The variation in calculation results caused by the variation in models, parameters, allocation rules etc. might be larger than the calculated reduction of GHG emissions from these models. This, in turn, can lead to a debate about the effectiveness and magnitude of mitigation options.
To stimulate benchmarking and exploring and identification of mitigation options in a precompetitive setting, a higher level of uniformity in modelling biological processes and calculating GHG emissions would enhance the effectiveness of the results and might lead to more clarity and less confusion. Although uniformity cannot be enforced by a single project, the process of coming to a more uniform approach has been started by stimulating the international discussion about emission calculation rules and by actively seeking contacts with similar projects in Europe and elsewhere.

1.5 A readers' guide for the report

First, we describe in chapter 2 the whole process of feed production and utilization, from seed production, cropping, processing, transportation to feed utilization in various livestock systems. This qualitative description provides an overview of the different aspects we took into account. Second, we describe in Chapter 3 the general aspects of the methodology, based on international guidelines for using LCAs. Although a GHG emissions analysis is a single-issue limited LCA, general guidelines are still of importance.
Third, in chapters 4–8, we elaborate on a number of items from the previous chapter. The relationship between the chapters is shown in Figure 1. Finally, in chapter 9 we discuss a number of methodological choices, and explain the sensitivity analysis, and describe and discuss a number of results.

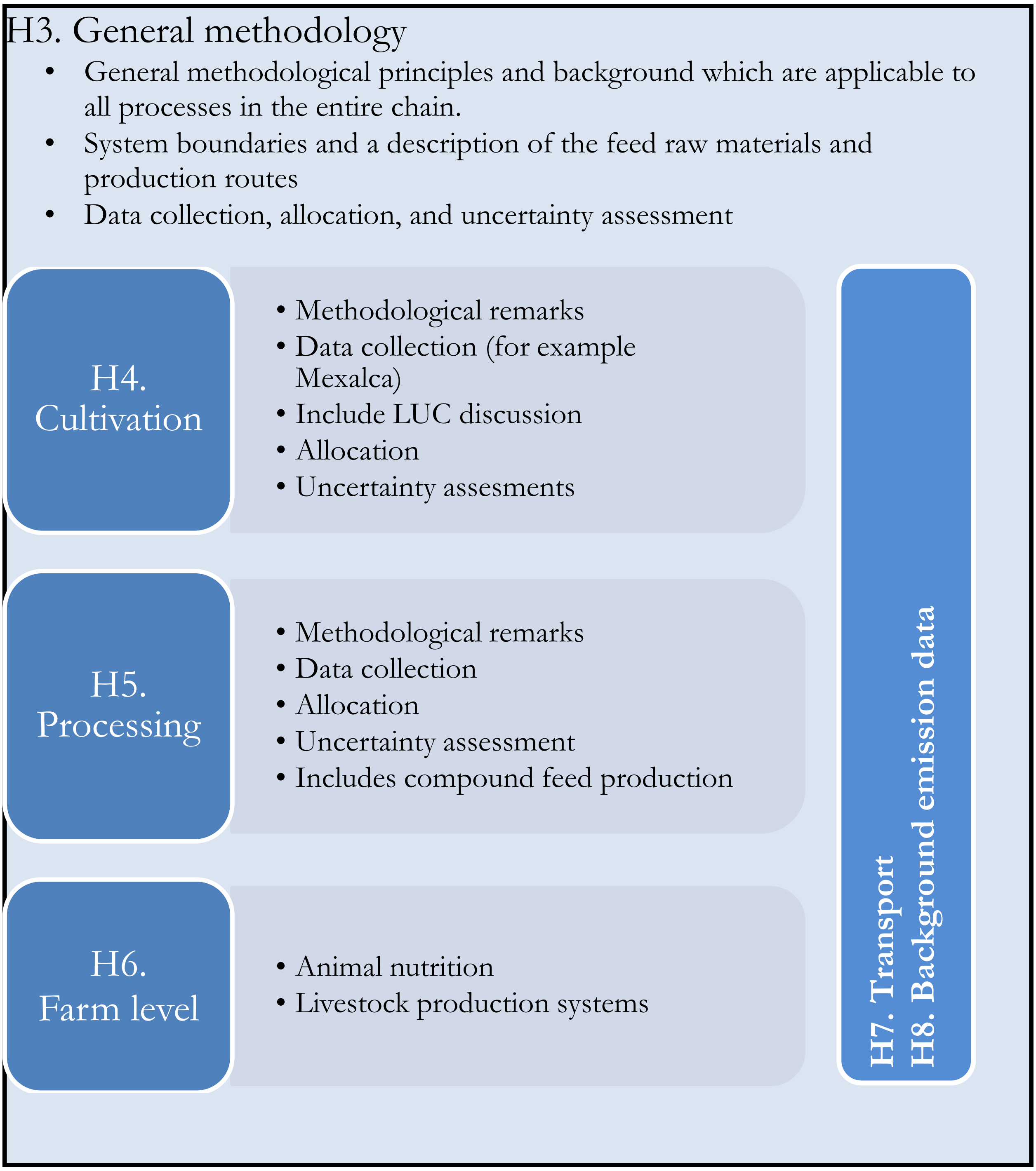


Figure 1. Structure of the methodology report of the Carbon Footprint Animal Nutrition

2 Overview of processes in feed production and utilization

2.1 Breakdown of the production chain

The GHG emissions of animal feed describes all relevant processes in the upstream production of feed materials and in the downstream utilization of feed by animals in commercial animal husbandry systems. Figure 2 from phase 1 of this project (Blonk & Ponsioen, 2010) shows all steps in the complete livestock production chain, from crop production to final production of meat, milk and eggs by animals and the storage and application of animal manure. Processes in feed production and the choice of raw materials can affect the nutritional quality and hence the conversion of feed to animal products and the manure production and quality. Therefore, it was decided in the first phase of the project that a proper assessment of the GHG emissions should contain both feed production and feed utilisation.
The calculation tool calculates the GHG emissions of feed raw materials from plant and animal origin, with the vast majority of the materials being from plant origin. Feed additives are not considered in this project.

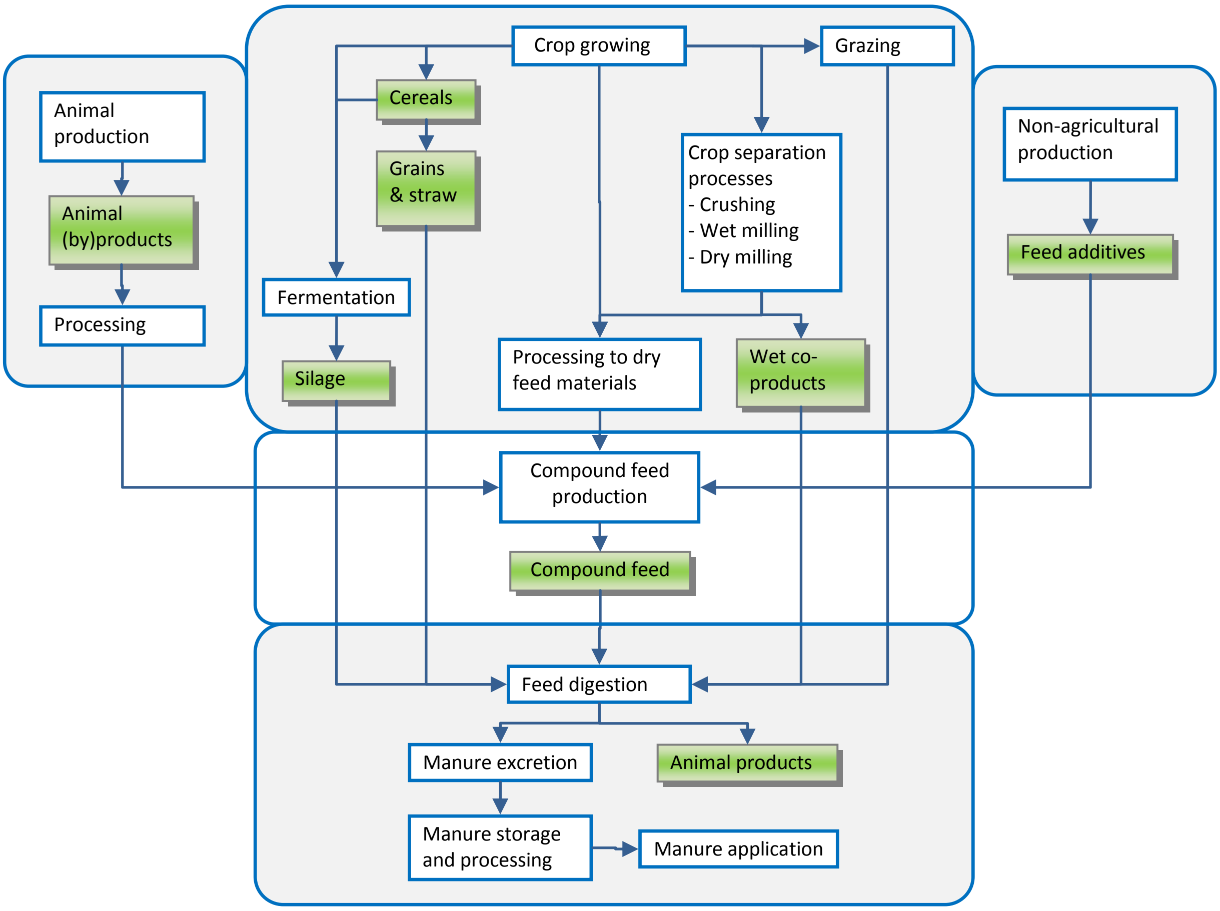


Figure 2. The overall flow chart of the complete production chain from the production andprocessing of feed materials and the final utilisation of feed by animals. The green blocks represent feed materials, Source: Blonk and Ponsioen, 2010.

2.2 Breakdown of the upstream process

There is a wide variation of feed materials in livestock systems. Fresh grass, for example, is ingested directly by the grazing ruminant (Figure 3, arrow on the extreme left), whereas conserved grass or other roughages are produced, generally stored on the farm, and subsequently consumed (the second arrow from the left). Compound feed consist of a number of components, originating partly from crops directly and partly from industrial processing of crops for food or technical use (the third and fourth arrows from the left). Co products from industrial processing can also be used on the farm directly (the

arrow on the extreme right). Most of the feed materials originate from crop production, but also animal by-products from slaughter and processing milk are important sources. The number of non-agricultural and mostly synthetic products (e.g. synthetic ammonic acids) is very limited. Every link in the chain is using inputs and energy for its own specific processes. There is always transport and storage between two links in the chain. Transport distances can range from less than 1 kilometre to thousands of kilometres.
The GHG emission of a specific feed material depends on many factors, on one hand on importance of various steps between production and utilisation, and on the other hand on the use of inputs and other activities (e.g. field operations) in each step.

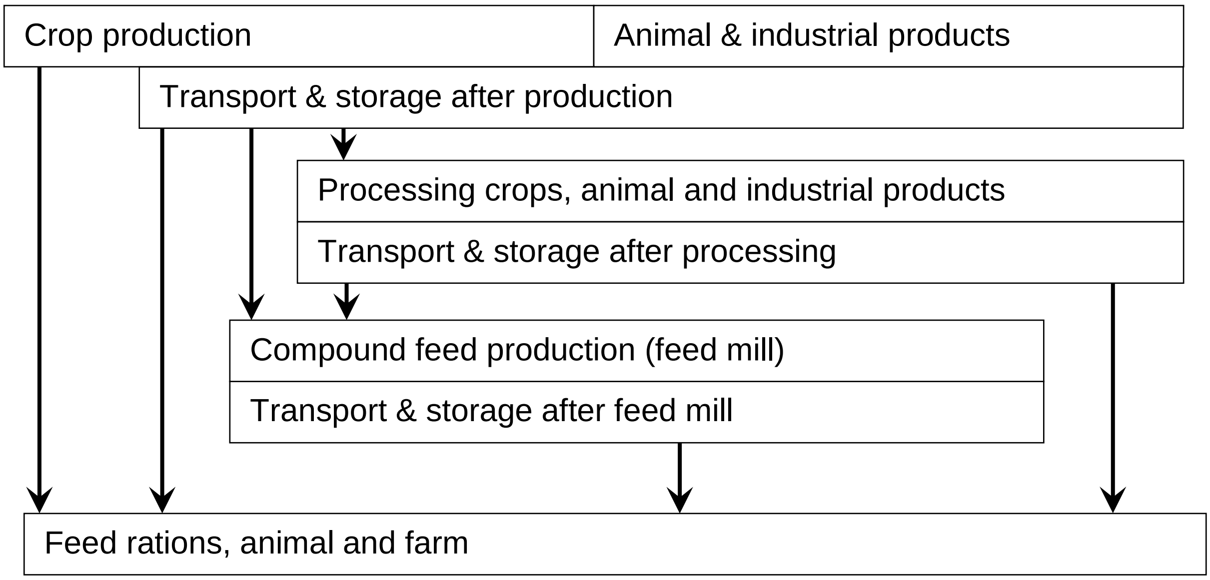


Figure 3. The flow chart describing the links in the production and processing chain of feed materials for livestock

In all links of the production chain we can distinguish inputs, activities and side effects, all having their own emission characteristics. For the calculation of emissions, calculation rules and input data are required. They will be discussed for each link in detail in chapters 4 to 8. The calculation rules are explained in those chapters as well. The default values of the input data will be discussed in a separate report.

2.3 Breakdown of the downstream process

Finally, all feed materials will be used on a livestock farm. Some feed materials are very specific, e.g. such as fresh grass that is used only by ruminants, whereas other feed materials can be a component of different types of compound feed, for ruminants, pigs or chicken. We know that different species (e.g. cattle, pigs, chicken) show differences in efficiency of feed use, which affects related GHG emissions (De Vries and de Boer, 2010). Moreover, feed quality affects efficiency of feed utilisation, the animal performance and, therefore, the related GHG emissions per kg of output (e.g. Gerber et al.., 2010). It means that a GHG emission of feed utilisation can only be given when a complete ration is defined. A potential emission per feed component is useless.

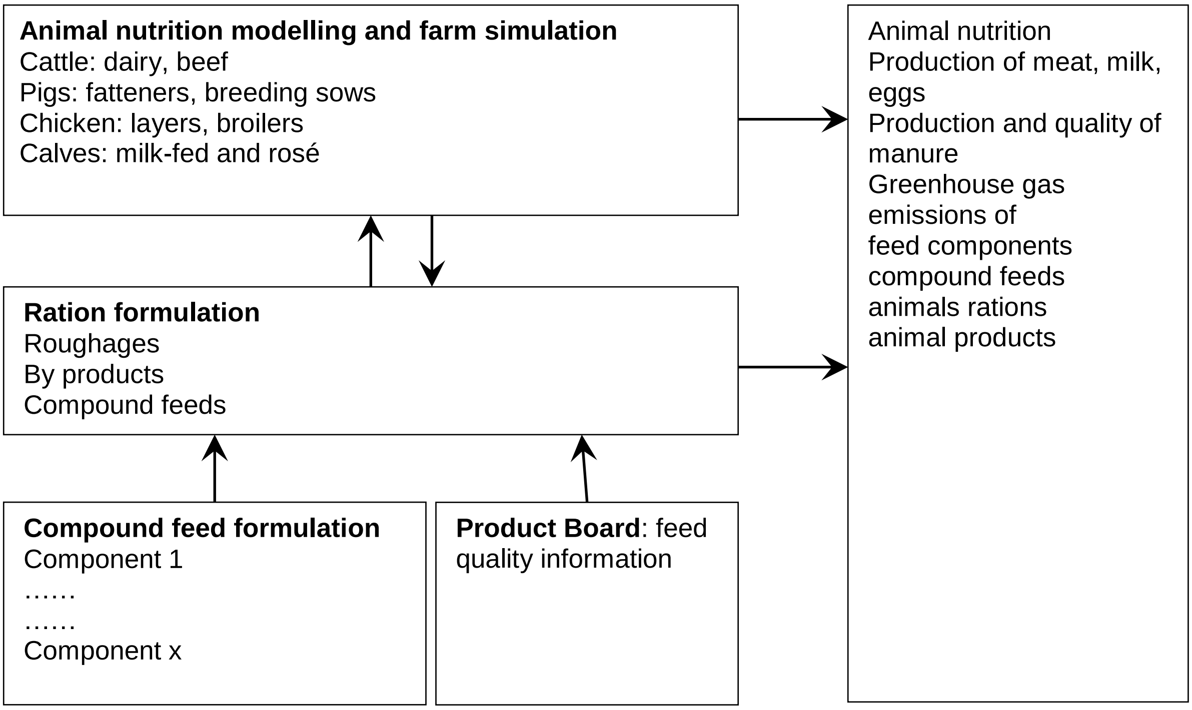


Figure 4. The flow chart for the definition of animals rations and the calculation of the feed utilisation by the animal, the production of milk, meat and eggs and the production of manure

To calculate final GHG emissions, the animals ration must be defined, including the composition of the compound feeds (see Figure 4). Emission calculations are done at the level of the livestock farm. Because feed conversion, animal performance and related GHG emissions per kg of product (live weight, milk or eggs) depends on the feed quality and the feeding strategy, we used simulation models to determine the relation between feed quality, feeding strategy and animal performance, resulting in a variable feed conversion. The use of a fixed feed conversion per animal does not reflect changes in feed composition and quality and, is, therefore, should not be used to calculate GHG emissions along the livestock chain. A number of farm conditions related to housing, manure storage types etc. will be set at default levels. Emission calculations of the livestock farm are described in chapter 6.

3 General methodological aspects of LCA

3.1 The position of the project "Carbon Footprint Animal Nutrition" in LCA GHG standards development

Life Cycle Assessment (LCA) is a method for an integrated analysis of environmental impacts along the life cycle of a product (Guinee et al.., 2002). Such an assessment may involve a wide range of environmental issues, such as eutrophication, acidification, climate change, use of land use or fossil fuels, or just a single issue, such as climate change. In this project, the focus is on the assessment of contribution to climate change, and we narrowed the scope to the emissions of three greenhouse gases CO_2, CH_4 and N_2O. The ISO standards (14040/44) provide the generic framework for conducting LCAs. These ISO standards have a global coverage. A specific standard on calculating GHG emissions is underway and its publication is expected in 2012. At the European level, a widely used interpretation of ISO 14044 for the calculation of GHG emissions by industry is PAS 2050 (BSI, 2008 and updated in 2011). In the PAS update of 2011, much attention has been paid to its alignment with the GHG protocol on LCA of products, which was drafted at the same time.
For biofuel production, a set of guidelines for emission calculations is defined in the Renewable Energy Directive (EU, 2009). Guidelines for calculating GHG emissions of dairy production have been developed by the International Dairy Federation (IDF, 2010) On the national scale, a horticulture protocol for calculating GHG emissions has been defined in 2009. This methodology is now formalized in an international PAS specification on horticulture (PAS2050-2011-1). Finally, all LCA methods have to be consistent with IPCC requirements on calculating GHG emissions on a national level (the National inventory reports (NIR). The position of the reported project in the "field" of standards is shown in Figure 5.

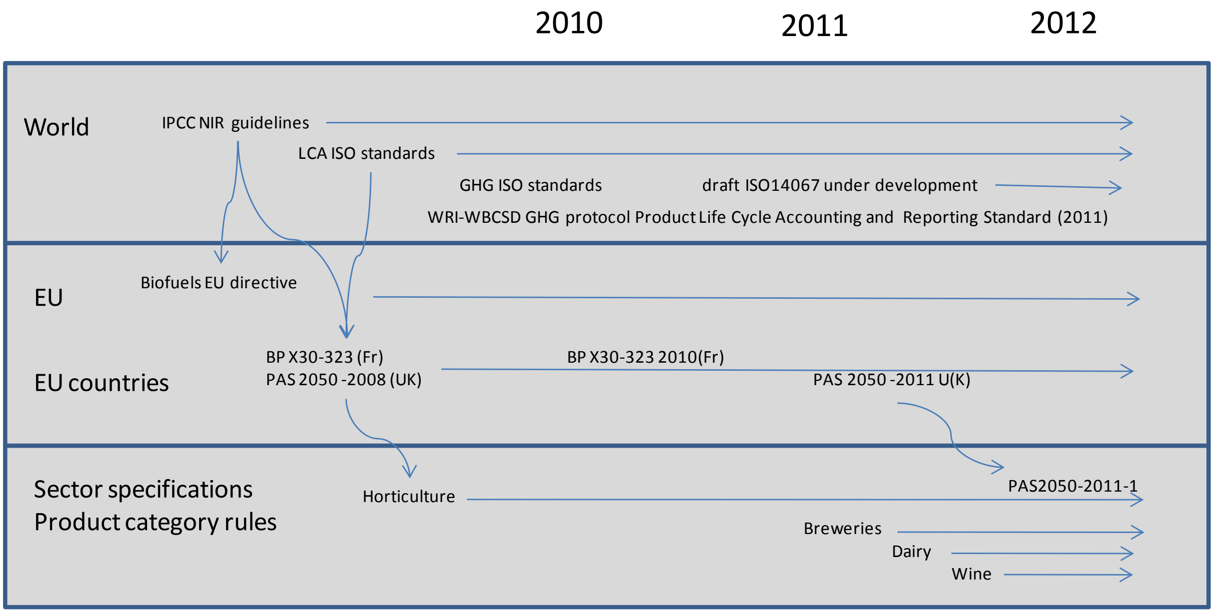


Figure 5. The interrelationships in the development of standards for LCA. Source: derived from Blonk and Ponsioen (2010)

The first steps in performing an LCA are the definition of the scope of the analysis, the functional and reference unit(s), the process maps, the system boundaries and the calculation rules. The scope of this analysis, the functional units, the system boundaries and method of allocation used are defined in this chapter.
Because the calculation rules in biological systems require a set of models, these are discussed in a separate chapter.

3.2 Scope of the GHG assessment of feed and the use of the tool

Many LCA GHG assessments on livestock products have been done (see also chapter 2). The contribution of feed is substantial, but varies between livestock species and between systems. At a high aggregation level, mitigation options for reducing GHG emissions have been discussed (e.g. Smith et al.., 2008). Defining mitigation options at an operational level for the feed production part of the livestock production chain requires an appropriate well defined assessment of current production systems. This can be realized by detailed studies at farm level (e.g. Schils et al.., 2007, Vellinga et al.., 2011) or at the level of industrial plants (Kranjc, 2007; EC, 2006). The use of primary data and site specific emission factors is very helpful in a good assessment. But when the effectiveness of mitigation options in a number of production chains have to be compared or when the effects of a mitigation option in the various links of the chain have to be assessed, a more uniform approach is required. When mitigation options are explored in a precompetitive setting, a uniform approach with general emission factors and default data is helpful.
<u>Therefore the project will assess the current GHG emissions of the livestock production chain with the focus on the production of feed materials for all essential livestock sector in the Netherlands. This report describes the methodology of data collection and calculating emissions. The default data are reported separately and a protocol and a user's guide support the application of the tool. The calculation tool FeedPrint with the GHG assessment will provide insight in the magnitude of the emissions and in the relative contribution of the different processes and activities in the whole production chain. An attributional life cycle assessment is the most appropriate tool for such an analysis.</u>

The GHG assessment of feed products with FeedPrint is primary meant to be used by organizations that formulate feed products (either in a factory or on the farm) to:

- allow internal assessment of the existing life cycle upstream GHG emissions of feed products;
- give support in the evaluation of alternative feed configurations, sourcing and manufacturing methods, raw material choices and supplier selection on the basis of upstream life cycle emissions of feed ingredients and feed formulation;
- create a benchmark for ongoing programs aimed at reducing GHG emissions;
- support reporting on corporate sustainability

The primary focus of the calculations, therefore is to estimate absolute levels of GHG emissions along the chain, and the breakdown of chain emissions into life cycle stages and emission sources (CO_2, CH_4, N_2O). This information is crucial for defining hot spots (i.e. major areas for improvement) and monitoring progress. Furthermore, this information is a helpful starting point to identify mitigation options, because the possible reduction can be related to overall emissions. This makes the monitoring of progress and setting of targets much more comprehensible. We, therefore, have chosen an attributional LCA approach, which implies that FeedPrint quantifies the environmental impact in a status quo situation (Thomassen et al.., 2008). LCA results from an attributional analysis, give insight into major areas for improvement, and, therefore, can be used to identify mitigation options. Moreover, the environmental impact of a new (status quo) situation, in which the mitigation is applied, can be explored using such a tool. To evaluate all environmental consequences of changing from the old to the new situation, however, a consequential LCA is more appropriate. A consequential LCA quantifies the environmental consequences of a specific change (e.g. a mitigation).
This is the reason that we choose for the wording, " give support in the evaluation" in the second bullet point of purposes, instead of " calculating the impact".

Example: If FeedPrint would calculate that a feed product would have a better GHG score when the feed material "beet pulp" is replaced by a mixture of grains, it is an estimation based on attributed GHG emissions, which is only valid within the context of the 4 defined purposes.
However, if the actual replacement of beet pulp takes place on a large scale and would invoke the introduction of an alternative use of beet pulp (for example as a biofuel) and the extra production of grains for replacement. The implications of the actual changes should be modelled in a consequential LCA to assess all impacts related to a change in feed ration (Thomassen et al.., 2008).

3.3 Functional units and reference units

In FeedPrint not one specific single functional unit is defined. The reference unit is a quantity of a certain feed with its specific characteristics and raw materials composition that can be related to GHG emissions of upstream feed materials production and downstream GHG emissions of feed formulation and feed utilization at the animal level. No variation in farm conditions (housing, manure storage etc.) is considered. This implies that the GHG assessment of the impact of feed preferably should be done on a combination of three different levels:

1. Feed products as being provided by the farm (upstream life cycle of feed materials, in fact a cradle to feed material analysis)
2. Feed products as being consumed by the animal (full life cycle of feed rations, the cradle to ration analysis)
3. Farm products as being produced from feed (full life cycle of feed converted into a default animal product, the cradle to the farm gate analysis)

The following default animal farm products are defined for the calculation of the full lifecycle emissions:

- 1 kg of live weight in the case of production for meat.
- 1 kg eggs
- 1 kg FPCM (Fat and Protein Corrected Milk, 4.0 % fat and 3.4 % protein).

For each animal product, we assumed the most common Dutch farming system, implying an average housing type, average manure storage facilities etc.
Beside meat, slaughter co products, such as skin, bones, intestines etc., are a substantial part of slaughtered animals. The partitioning of the whole animal over the wide range of main and co products on a mass and an economic basis is complex and is not included in this study. FeedPrint, therefore, follows a cradle-to-farm gate LCA approach, implying a functional unit for meat of 1 kg of live weight of a specific animal , for eggs of 1 kg of fresh eggs, and for milk 1 kg of FPCM leaving the farm-gate.

3.4 Definition of feed raw materials and countries of origin

One of the aims of the project is to generate a default database on feed raw materials, that is used in FeedPrint. We took the CVB table of raw feed materials as a starting point. This table can be categorized into five groups (Table 2).

Table 2. The classification of feed raw materials and the numbers per group as used in thecalculation tool of the CFPAN project

	Number of feed raw materials
Dry feed materials of vegetable origin	152
Dry feed materials of animal origin	30
Wet co-products from industry	36
Fresh crops “not suitable” for food production	50
Fresh feed produced at farm (grass maize silage)	79
Total	347

Based on information from stakeholders, we made some changes to the CVB table, see below:

1. The working group Animal Products proposed to be more specific about feed raw materials obtained from category 3, namely rendering and blood processing. In the CVB table these products are listed as ”animal fat and meal" and “blood meal”.
   a. The working group proposed to substitute “animal fat and meal” by 3 types of animal fat and meal and 2 types of animal fat and greaves:
      i. Pig fat and meal
      ii. Chicken fat and meal
      iii. Cow fat and meal
      iv. Bovine fat and greaves
      v. Chicken fat and greaves

   b. “Blood meal” from the CVB-table is substituted by 4 blood products:
      i. Haemoglobin powder from porcine blood
      ii. Plasma powder from porcine blood
      iii. Haemoglobin powder from bovine blood
      iv. Plasma powder from bovine blood
2. Co-products from the dairy industry are classified into 7 feed-raw materials. Lactose and permeate are added to the list; and there are 3 types whey protein concentrates added to the list.
3. Soy protein concentrate was added to the list

Due to the changes in the list of feed materials of animal origin, an overview is provided in Table 3. A detailed list of all feed materials of plant origin is in Appendix 1.

Table 3. Overview of the animals product used in the calculation tool of the CFPAN project

CVB product	Changed into or substituted by
Feather meal hydrolysed	Feather meal hydrolysed
Animal fat and meal	Pig fat and meal
Animal fat and meal	Bovine fat and meal
Animal fat and meal	Chicken fat and meal
Animal fat and meal	Pig fat and greaves
Animal fat and meal	Bovine fat and greaves
Animal fat and meal	Chicken fat and greaves
Blood meal	Haemoglobin powder from porcine blood
Blood meal	Haemoglobin powder from bovine blood
Blood meal	Plasma powder from porcine blood
Blood meal	Plasma powder from bovine blood
Casein	Casein
Milk powder skimmed	Milk powder skimmed
Milk powder whole	Milk powder whole
Not in CVB table	Lactose
Not in CVB table	Permeate
Chees whey CP >275	Whey (30% dry matter content)
Whey powder	Whey powder
Whey powder MSA	Whey powder delactosed
Whey powder low in sugar Crude ash < 210	Whey powder low in sugar Crude ash < 210
Whey powder low in sugar Crude ash > 210	Whey powder low in sugar Crude ash < 210
Not in CVB table	Whey protein concentrate (30%)
Not in CVB table	Whey protein concentrate (60%)
Not in CVB table	Whey protein concentrate (80%)

<u>Countries of origin</u>
Over 80% of the feed raw materials used in the production of feed concentrates in the Netherlands are cultivated abroad. Some feed cereals , e.g. wheat, barley, triticale and oats, are grown in the Netherlands, whereas most origin from France and Germany, and, to a lesser extent, from other European countries. Rapeseed meal originates mainly from Germany and France. Soybeans are cultivated and processed mainly in South and North America, although some soybeans are first shipped and subsequently processed in Europe. Oil palm products, like palm kernel expeller, come mainly from Southeast Asia. Molasses comes from sugar cane processing in South America or Pakistan, and from sugar beet processing in the Netherlands or other European countries. Dairy products (e.g. whey powder or whey protein concentrate) come mainly from Dutch milk production. Within this project, it appears not feasible to collect cultivation data for each country that exports agricultural commodities to the Netherlands. To make a sound estimate of the GHG impact of feed raw

materials in the default database, we focused on those countries that account for the major share of the Dutch import for feed raw materials. For each crop, we tried to include those countries that in total were responsible least 80% of the feed raw materials used by the Dutch feed industry. In some cases, however, there was lack of data to determine where the arable products used in the Dutch feed industry were cultivated. The feed industry buys goods from all over the world and knows the location of their suppliers. However, the countries of the suppliers are not necessarily the countries where the products are cultivated.
Additionally, we searched for export and import data at FAOstat (www.fao.org). Among others, FAOstat contains data about annual production, import and export of agricultural goods. FAOstat, however, contains trade-information, but does not contain information of the origin of countries from which agricultural commodities are imported. A country that produces a large amount does not necessarily export much and vice versa. In 2009, the Netherlands, for example, was the 6th largest export country of soybeans, whereas soybeans are hardly cultivated in the Netherlands. The annual production and the amounts of export and import are taken into consideration to rank countries and to estimate their share in export to the Netherlands. We assumed that countries that produce and export much can be considered of more importance for the Dutch feed industry than countries that do not produce and export much. The most important countries are selected for data collection. The number of countries per crop varies between 1 and 6. If cultivation data of a crop in a specific country could not be found, we choose another country. Table 4 shows the crops and countries that are taken into account.

Table 4. Crops and animals and the producing countries that are taken into account

Primary product	Countries
1. Cereal grains	
Barley (brewers' and fodder barley)	Germany, France, Belgium
Corn/Maize	Germany, France, USA, Hungary, Brazil
Millet	India, Nigeria, Niger
Oats	the Netherlands, Belgium
Rice	China, India, Indonesia, Viet Nam
Rye	Poland, Germany
Sorghum	USA, Argentina
Triticale	Germany, the Netherlands, France
Wheat (bread and fodder wheat)	Germany, France, the Netherlands, United Kingdom
2. Oil seeds and oil fruits	
Coconut	Indonesia, Philippines, India
Cotton seed	USA
Hemp	China, France, Chili
Linseed	Australia, Germany
Niger seed	Unknown
Oil palm	Indonesia, Malaysia
Peanut/Groundnut	China, USA, Brazil, Argentina
Poppy seed	Czech Republic, Turkey, Spain, France
Rapeseed	Germany, France
Safflower seed	India, Mexico, USA, Argentina, Turkey
Sesame seed	India, China
Soybean	Argentina, Brazil, USA
Sunflower	China, Argentina, Ukraine, France
3. Legumes	
Beans, horse beans, field beans	Germany, France
Lentils	Canada, USA, Turkey
Lucerne	France, Germany, the Netherlands
Lupines	Australia, Germany
Peas	Germany, France, Australia

Primary product	Countries
4. Roots and tubers	
Cassava	Thailand
Chicory	Belgium, the Netherlands
Fodder beet	the Netherlands
Potatoes human consumption	the Netherlands, Germany, Belgium
Starch potatoes	the Netherlands, Germany
Sugar beets	Germany, the Netherlands
Sweet potatoes	Uganda, China, USA
5. Other seeds and fruits	
Buckwheat	China, Poland, Brazil
Canary seed	Canada, Thailand, Argentina
Citrus fruits (Oranges)	Brazil, USA
6. Forage and roughage	
Grass and clover	the Netherlands
Lucerne	the Netherlands
Maize	the Netherlands
7. Other plants and fruits	
Apple, pear, endive, gherkin, cucumber, cabbage, pepper, leek, lettuce, spinach, tomato, onion, chicory, carrot	the Netherlands
Sugar cane	Australia, Brazil, India, Pakistan, USA, Sudan
8. Milk products	
Milk	France, Germany, Belgium, the Netherlands
Whey	France, Germany, Belgium, the Netherlands
9. Feed ingredients from land animals	
Feather meal hydrolysed	the Netherlands, United Kingdom, France, Italy
Animal fat, meal, greaves	the Netherlands, Germany, France, Belgium
Blood products	the Netherlands, Germany, France, Belgium
10. Fish products	
Fish meal	Germany, Denmark, Peru, Norway, Chilli
Fish oil	Norway, Scotland, Peru

3.5 System boundaries

There is an interaction between the scope of the study, the functional unit and the system boundaries. Within the scope of the GHG assessment of feed, three different levels were identified: a) the upstream life cycle of feed materials; b) the upstream life cycle of feed rations and c) the full lifecycle of feed converted into animal products (upstream and downstream). The latter is the cradle to farm (back) gate analysis.

<u>Upstream boundaries</u>
Upstream emissions have to be incorporated in the total emissions. In theory this is an almost infinite job, because it ends with the mining and processing of e.g. fuels and steel, and similar processes far upstream the production chain. Therefore a set of so called cut-off rules have been defined. Beyond this point where cut-off is applied no emissions are calculated, but based on information in databases. This is the case for the use of machinery, fuels, fertilizer production etc. Direct emissions related to machinery use in crop production (e.g. diesel for tractors) are calculated on the basis of their direct fuel use, but the indirect emissions related to the production and maintenance of machinery are taken from an LCA database. We chose to use Ecoinvent as the databases for this type of emissions. Furthermore, we excluded impacts related to production of capital goods used in processing industry, feed mills and farm buildings from our GHG analysis. The differences between the types of mills and

farms are considered to be very small, which means that they will not affect the differences in GHG emissions between commodities. An overview of the processes and activities contributing more on average than 1 % of the total GHG emissions is shown in Table 5. These emissions are incorporated in the calculations in FeedPrint.

Table 5. Processes and activities contributing on average more than 1 per cent of the total GHG emissions from feed production and feed utilisation.

Stage	Use of inputs or biological conversions	Production of inputs
Crop production	Seed, plant material	N fertilizers: N2O, CO2
	Synthetic N fertilizers: N_2O	Other fertilizers: CO2
	Urea: N2O, CO2	Energy carriers: CO2
	Manure: N2O	Limestone: CO2
	N fixation: N2O	Seed and plant material: CO2, N2O
	Liming: CO2	
	Crop residues: N2O	
	Burning crop residues: CH4, N2O	
	Fossil energy carriers: CO2	
	Electricity: CO2	
Crop processing	Biogenic energy carriers: CH4, N2O	Energy carriers: CO2
	Fossil energy carriers: CO2	Auxiliary materials: CO2
	Auxiliary materials: CO2	
Products of animal origin	Full GHG LCA	Full GHG LCA
Products of industrial origin	Not considered	Not considered
Compound feed production	Fossil energy carriers: CO2	Energy carriers: CO2
Livestock production	Enteric fermentation: CH4	Energy carriers: CO2
	Manure management: CH4, N2O (direct/indirect)	
	Fossil energy carriers: CO2	
Manure application *(Potential emissions)*	Emissions N2O (direct/indirect)	Energy carriers: CO2
	Fossil energy carriers: CO2	
Transport between stages	Fossil energy carriers: CO2	Energy carriers: CO2

<u>Downstream boundaries</u>

The downstream boundaries are defined by the farm gate. Downstream processes in slaughtering animals, processing milk and eggs are not incorporated. Because cycling nutrients is an essential element of agriculture, animal manure at the farm will be used in a next production cycle. Because the scope is on the feed production and utilization, manure is considered to be at the start of the production chain. Because manure is not considered to have embedded emissions, the only emissions at the start of the production chain come from application.

This implies that also in the case of land based ruminant systems there is no link between the application of manure on grass and silage maize and the production of the manure at the farm level. It is known that the quality of the animals' ration affects manure quantity and quality (e.g. van Duinkerken et al.., 2005). Exploring mitigation options in the whole production chain might also affect the feed ration's quality and hence the manure production and quality. It is therefore that potential emissions of manure application will be calculated, but not incorporated in the GHG emissions of animal production.

3.6 Basic allocation principles

Many processes in the livestock production chain have multiple outputs. Some of these multiple outputs are mutually dependent, and cannot be divided. A milking cow, for example, also produces some meat and generates newborn calves, that can be used in the veal calf industry. This issue of mutual dependence also plays a role regarding, for example, use of manure (an input) for crop production, as as manure not only affects crop growth in the year of application, but also in subsequent years.

Because the aim of FeedPrint is to compare GHG emissions of single products (a feed, or a kg of eggs), we have to partition impacts of a process along its chain to its mutually dependent outputs, a process well-known as allocation. The basis of allocation is partitioning of the total emissions of a specific process to its diverse outputs. Allocation is not about increasing or reducing emissions, but only about partitioning of emissions. It also means that the emission of a single output, coming from a process with multiple outputs, always should be considered as an output of a complete system. The single output cannot be isolated. It is impossible to produce rape meal without producing oil. No milk can be produced without producing meat from the cow or producing a calf. So reducing the GHG emissions of a single product by allocation implies that the inevitable other product(s) will have increased GHG emissions. Changing the allocation does not change the system and hence does not reduce the total GHG emissions of the process.
Allocation can have a very large effect on the GHG emissions of products. However the implications for the different co-products can vary greatly. E.g. in the case of dairy cattle systems, the allocation between milk and meat can range from 95 – 80 % to milk and the remaining percentage to meat. The GHG emission level of milk changes slightly, but the GHG emission level of meat is strongly affected (Gerber et al.., 2010).

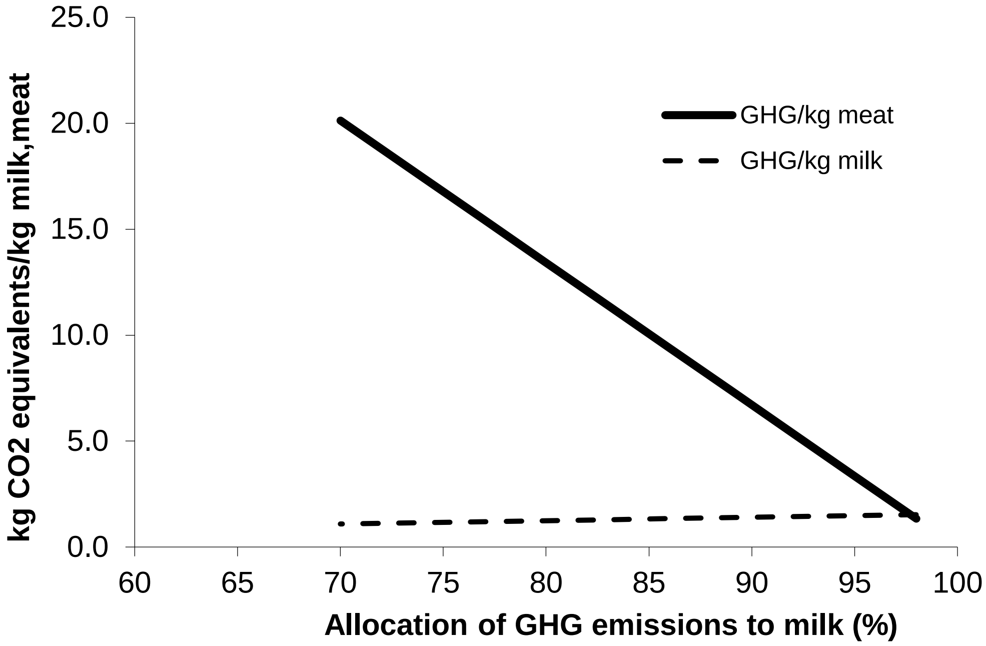


Figure 6. The GHG emissions of milk and meat (in CO_2-equivalents per kg of milk and carcass) in relationship to the relative allocation to milk and meat in a dairy system. Source: Gerber et al.., 2010.

Allocation can be done in different ways (Guinee et al.., 2002). The way of allocation has a big impact on the GHG emissions of feed materials (Blonk & Ponsioen 2010.
The allocation methodology applied in FeedPrint is based on the ISO rules (ISO 14044) on allocation and build further on the practical application of these rules to agricultural systems as defined in the Dutch horticulture protocol (Blonk and Ponsioen, 2009):

1. if backflow occurs in the system (closed loop recycling), the primary input should first be corrected? for the backflow
2. If the co-products have similar characteristics or functionality, allocation shall be based on one or more physical characteristics, such as mass.
3. If the co-products have distinct characteristics and or functionality, allocation shall be based on the economic value of the co-products.

We prefer to apply allocation based on the economic value of co products for two reasons:

- In industrial processing, raw materials (crops and animal products) are split up in a number of co products, often with a wide variation in nutritional, chemical and physical properties, in the related functionality and in the economic value. The process is designed to separate one or more specific main products from the crops: for instance oil, starch or protein. The co products are a mixture of the remaining fractions, such as "protein & carbohydrates" or "oil, proteins & fibres", etc. In a number of occasions the total mass of co products is larger than of the main product. Applying mass or energy content as an allocation criterion would lead to allocating the majority of the impact to the total co product fraction while the process was designed to separate a single component, the main product.

- Co-products of separation processes consist of many different chemical substances that each may have a positive or negative contribution for the purpose they are used for. For co products being used as feed, the value is determined by nutritional characteristics, which differs per animal type, and " the position" of the feed in the overall ration of the animal. The decision to use co products for food, feed or fuel is based on the combination of price and technical suitability. "Value" cannot be derived of feed nutritional properties only. Hence, the actual functionality and value of a feed raw material is determined by the context of the overall production system in a certain region at a certain time.

Next to economic allocation, feed industry and the feed production chain must be able to apply other allocation methods. First of all because of the methodological consideration to apply a sensitivity analysis on allocation when interpreting the results of calculated improvement options.

Furthermore, industries being part of the feed production chain may have a need for calculating different allocation options. For example, many companies have to conduct calculations for the production of biofuels according to the requirements of the Renewable Energy Direction that prescribes an energy based allocation. Feed is often the other co-product here. So that would mean that they have to use different allocation methods for the same production process.

Therefore the CFPAN tool provides the option to calculate next to the economic allocation GHG emissions based on mass and on energy content.
The energy content allocation is based on the Lower Heating Value of the dry matter of the different co-products. Evaporation of water is not taken into account. The mass based allocation is done on the basis of dry matter content.
It should be noted that the prices of raw materials are not relevant as such. The prices of co-products only matter in relation to the estimation of the value in the total revenue of a food production operation in a certain time frame in a certain region. The prices needed for economic allocation are typically average prices over a certain time period and should not be adapted too frequently. No LCA standards do give any guidelines on how to deal with updating allocation factors. For the CFPAN tool and database we assume that an update once in two years is sufficient. The precise method of economic allocation and the prices used is further explained in chapters 4 and 5.

3.7 Data

Emissions are calculated according the basic model:

$E = \sum(AR * EF)$

in which:
E = Emission in grams
AR = the amount of input or activity, expressed in a reference unit
EF = the emission factor, expressed as gram / reference unit

In this equation, two types of data are used: a) the foreground or primary data, expressing the amount of inputs, activities etc., the AR in the formula and b) background or secondary data, expressing the emission factors per unit of activity or input, the EF in the formula.
Foreground or primary data in the case of the feed production chain are e.g. the yields of crops, fertilizer rates, hours of machinery use, amount of energy use in industrial processing etc. They can be affected by management. The background data are the emissions for the production and application of inputs and activities such as fertilizers, pesticides, the emissions for the use and maintenance of machines. In theory, background data can be changed, but they are outside the scope of this study.

General methodological starting points for collecting foreground and background data are:

- Consistent approach to ensure comparable calculation of GHG emissions for all feed materials. Consistency implies the use of the same data model for similar processes, completeness of data, applying the same criteria for data quality and a uniform approach for assessing missing data;
- For each parameter an uncertainty estimate is determined to facilitate a Monte Carlo uncertainty assessment (see also the paragraph on dealing with uncertainty).
- Capital goods are included for transport means and agricultural equipment, but not for production plants, based on materiality of the contribution.
- Other raw materials and consumables in processing are only included if previous LCAs proved that they have a material contribution.

Data collection was a two-step process. The first step was to collect data from the public domain (Scientific literature, FAOstat, Eurostat, etc.) including public research results from Blonk Consultants and WUR. As the project involves a large amount of animal feed raw materials that have not been previously thoroughly studied, many cases arose in which the data from public sources turned out to be insufficient. With the available data, reports were prepared on cultivation and industrial processing for feed raw materials. The second step was to discuss the draft reports with experts from industry mainly from the feed industry stakeholders of CFPAN working group, or otherwise from authors identified from their publications on specific subjects. The aim was to collect feedback on the contents of the reports in order to check and extend the data.

Data quality indicators

A lot of data is obtained from many different sources and at some point obviously a choice has to made for a certain value (or an average of values) as the most representative to be used in the life cycle assessment. This paragraph aims to clarify how we assessed the quality of the data encountered in literature sources. The quality of the available date sources also impacts the choice for the type of uncertainty distributions as described above.

When evaluating the representativeness of an article or other type of document for our specific cases, questions can arise like: do the time periods match? Does the geography discussed in the literature correspond to our case? What about appropriateness of the technology? To establish a kind of format around these types of questions, it is necessary to develop a quality assessment tool that can be used within this research.
The method of data quality assessment used in Ecoinvent is very reliable. We have used their *Pedigree*[1]-matrix of data quality scoring criteria, but we do not strictly rely on the quantitative uncertainties connected to this matrix.

Data quality assessment according to Ecoinvent

According to Ecoinvent (Hischier et al.., 2009), as well as the GHG protocol (WRI-WBCSD, 2011), literature is assessed according to five characteristics. We have slightly adjusted the meaning of the second indicator (completeness) to our specific needs, as it was not evident how to use this indicator in its former shape.

1. Reliability: how is the data measured?
2. Completeness: does it describe the whole activity?
3. Temporal correlation: does the time period correlate?
4. Geographic correlation: does the geography correspond?
5. (Further) technical correlation: is a similar technology used?

Each data entry gets a number assigned between 1 and 5 for each indicator by the person entering the data, according to a prescribed meaning of each value, as can be seen in **Table 6**. Although these indicators are important in order to be able to work consistently, they obviously do not provide any quantitative support need for the final LCA calculations. The Ecoinvent method does make an effort to formalize the uncertainty ranges stemming from an assessment of these indicators and some of these are employed in the uncertainty assessment in the sub reports. However, the uncertainty ranges employed will always have a strong subjective character.

[1] Pedigree: a document to register ancestry, used by genealogists in study of human familiy lines, and in selective breeding of animal (in Dutch: *stamboom*). Source: en.wikipedia.org/wiki/Pedigree.

Table 6. Pedigree matrix as adopted from Ecoinvent

Indicator score	**1**	**2**	**3**	**4**	**5 (default)**
Reliability	Verified data based on measurements	Verified data partly based on assumptions ***or*** non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	The data is representative for the process considered, over an adequate period to even out normal fluctuations	The data is representative for >50% of the process considered, over an adequate period to even out normal fluctuations	The data is representative for only part of the process (<<50%), ***or*** >50% but for shorter time periods	The data is representative for only one part of the process considered, ***or*** for small part of the process but for shorter time periods	It is not known which part of the process the data represents
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Less than 15 years of difference to the time period of the dataset	Age of data unknown or more than 15 years of difference to the time period of the dataset
Geographic correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions.	Data from area with slightly similar production conditions	Data from unknown ***or*** distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technical correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale ***or*** from different technology

Notes:

- Reliability: Verification may take place in several ways, e.g. by on-site checking, by recalculation, through mass balances or crosschecks with other sources.
  Includes calculated data (e.g. emissions calculated from inputs to an activity), when the basis for calculation is measurements (e.g. measured inputs). If the calculation is based partly on assumptions, the score would be 2 or 3.
- Completeness: The original descriptions were: (1) Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations; (2) Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations; (3) Representative data from only some sites (<<50%) relevant for the market considered ***or*** >50% of sites but from shorter periods; (4) Representative data from only one site relevant for the market considered ***or*** some sites but from shorter periods; (5) Representativeness unknown or data from a small number of sites ***and*** from shorter periods.

3.8 Dealing with uncertainty

Four types of uncertainty can be distinguished (Table 7): uncertainty regarding Global Warming Potentials, emissions models, methodological choices and data uncertainty. The current paragraph deals with data uncertainties. The uncertainties regarding methodological choices (for example, different types of computing direct or indirect N2O emissions, allocation choices) are partly explored by Van Middelaar et al.. (2012).

Table 7. Types of uncertainties and sources

Global Warming Potential	Climate change impact of the various greenhouse gases.
GHG emission models	Modeling of emissions of greenhouse gases from various activities. For example how land use change emissions are modeled.
Methodological	Uncertainties through methodological choices in the LCA calculations. These include choices concerning system boundaries and allocation.
Data	1) Foreground data related to energy use, material use, etc. 2) Background data used to calculate the GHG emissions from the foreground data

Considering the goal of FeedPrint, it is desirable to focus the uncertainty analyses only on the parts within the sphere of influence of the agricultural industry. A farmer, for example, can affect the amount of fuel or fertilizer used, but not the emissions from combustion or the way these emissions are allocated to the final feed raw material. Thus, the data for which uncertainty ranges were determined include only a subsection of the model parameters, and are shown in the table below. All available foreground data is subject to uncertainty assessment, while of the background data only the emissions related to the production of N-fertilizer is included (Table 8). The latter is included because of its large impact on the overall GHG emissions.

Table 8. Data included in uncertainty assessments

Foreground data	Background data
Material inputs during cultivation (fertilizers, pesticides, etc.) Cultivation yields Energy use (electricity, fuels) Mass balance industrial processing Auxiliary material input	Emissions related to production of N-fertilizer

These parameters were included in the discussion surround the assessment of uncertainties which is the subject of the remainder of this paragraph.
There are many sources for uncertainty, such as:

1. The data that are obtained vary in quality, reliability and completeness.
2. There is a large variation in production techniques, management of industrial processes, efficiency, etc.
3. There is a spatial and temporal variability of yields, both in cultivation as in processing.
4. Production techniques develop quickly, while data found in the public domain are related to earlier process techniques.
5. Market circumstances which can result in a shift of production, influencing the mass balance and allocation towards the co-products

<u>Monte Carlo</u>
For the parameters included in the uncertainty assessment, the well-known Monte Carlo method is applied. The life cycle assessment calculations are carried out multiple times where in each iteration a random set of parameters is chosen in order to execute the calculation. Other values which are not included in the uncertainty assessment remain the same in each iteration. This results in a probability distribution of GHG emissions characterized by a central value and a variation. The shape and size of the probability distribution is dependent on choices on distribution types for the parameters, as will be explained in section 3.8.2.

Guidelines

A number of guidelines include recommendations on dealing with uncertainty, a number of which are listed below. None of the standards dictate any particular choice of dealing with uncertainty. The final choice of dealing with uncertainty in the CFPAN project is for a large part based on the method applied within the Ecoinvent database, with added additional insights obtained in the course of the project.

ISO 14040/44 and PAS 2050

ISO only states that an uncertainty analysis is required. No details are defined.

IPCC

IPCC guidelines give examples of methods to analyse uncertainties. The guidelines do not recommend any of the methods being more appropriate.

Ecoinvent

Ecoinvent uses the pedigree matrix to estimate uncertainties (Standard Deviation etc.). Basic uncertainty factors are assumed to depend on the type of emission. Experts have estimated uncertainty factors for different types of input and output. These basic uncertainty factors are corrected for the uncertainty of the data source. Ecoinvent prefers to assume a log normal distribution.

GHG protocol (Product life cycle accounting and reporting standard)

The GHG protocol (WRI-WBCSD, 2011) gives general qualitative indications of uncertainty assessments and guidance on the type of uncertainties to be addressed. However, also here, no strict requirements are dictated.

Probability distributions and bandwidths

ISO, IPCC and PAS2050 provide directives or guidelines about how to deal with uncertainties. Like in many other LCA studies, we will apply a Monte Carlo simulation to calculate the best estimate and the lower and upper limit of the GHG emissions per reference unit. For an appropriate application of Monte Carlo it is necessary to know:

The probability distribution type of the parameter (for example a normal distribution)

The best estimate, standard deviation and/or the lower and upper limit, depending on the type of probability distribution.

Ecoinvent has a quite elaborate system of assessing uncertainties, which also includes a quantitative assessment based on the pedigree matrix (described in the next section). The bandwidths we have chosen to include in the model are based on those of Ecoinvent. From the list of four types of uncertainty distributions (Table 9), one is chosen for each parameter in the database based on the available data and insight. Detailed information about the distribution types is in the Appendix 2.

Table 9. Summary of uncertainty distributions

Distribution type	Description	Application
Normal	Gaussian symmetric distribution curve	When a best estimate or average value and insight in standard deviation is known and distribution around the mean value is not assumed to be asymmetric.
Lognormal	Asymmetric normal distribution	When a best estimate or average value is known, but the distribution is assumed to be asymmetric (and for example tails off to higher values).
Triangular	Peak surrounded by a min-max range	When a best estimate is known, but limited data indicates a strong asymmetric distribution surrounding this best estimate.
Uniform	Continuous between minimum and maximum	When limited data gives two distinctly different values and no information on the best estimate.

4 Crop production

4.1 Reference units and functional units

The functional unit of the phase of crop production has two functions: the first one is to be able to calculate the emissions related to the crop production itself and the second is to communicate with the other links in the entire production chain.
The functional unit in crop production is 1 kg of fresh product leaving the field, including the losses during harvesting and the losses at the first storage point. This means that losses and emissions after leaving the first storage point “on the road” belong to the next phase of the production chain.
Beside the emissions per kg of product, a number of characteristics are added to the product. They are essential in allocating emissions in later phases of the production chain. These characteristics are: content of dry matter, carbon and gross energy.

4.2 System boundaries

The system boundary is related to the functional unit and vice versa. In the case of crop production, the system boundary is set at the first storage point after leaving the field. For a number of products this will be the storage at the livestock farm itself (in case of on-farm feed production), in other cases this is a temporary central storage point.
The phase of the crop production includes:

- production of seed and young plant material
- production and application of fertilizers
- transportation and application of manure
- production and use of pesticides
- production and maintenance of equipment for cultivation
- fossil energy use for cultivation activities
- soil emissions of N_2O and CH_4 related to N-application and drainage of peat soils, etc.
- energy use and loss at storage before further use in industrial processing, compound feed production or utilization by the animal
- emissions related to land use and land use change

A number of activities are excluded:

- Emissions of oxidation of biogenic carbon
- All activities that are not directly related to production, such as living of the farmer, commutable traffic , etc.
- Transportation between all stages and for the provision of all inputs. The transport is calculated separately.

4.3 GHG emissions related to inputs and activities

A number of inputs are used for crop production, such as fertilizers, pesticides and fuels. These are really spent at the end of the production process. Some of the inputs cause GHG emissions during the spending phase, e.g. nitrogen causing nitrous oxide emissions and fuels leading to carbon dioxide emissions. Others, such as pesticides and phosphate or potassium fertilisers are not considered to produce GHG emissions during the spending phase.

<u>Machinery</u>
There are also inputs that are used but not (entirely) spent for the specific crop, such as machinery, used for ploughing, applying fertilizers etc. For machinery, direct and indirect emissions are distinguished. The direct emissions are related to the fuel used during ploughing, harvesting etc. The indirect emissions are the emissions due to the production phase and due to the maintenance, based on a number of working hours in its productive life according to Ecoinvent (Nemecek and Kägi, 2007). Detailed information is available in the documentation reports. An overview of the incorporated emissions related to crop production is shown in **Table 10**.
All inputs, whether they are spet entirely or not, require energy in their own production phase and cause related GHG emissions. Emissions related to production of seed, fertilizers and pesticides are

derived from databases and will be discussed in chapter 7. Emissions related to the production, depreciation and maintenance for machinery will be discussed in the Appendix 3. Emissions of nitrous oxide from nitrogen fertilizers, manure and crop residues and emissions of carbon dioxide from the use of fossil fuels for cultivation will be discussed in chapter 4.

Table 10. Emissions that are considered for all inputs and activities during crop production.

	Emissions at production	Emissions at application/use	Emissions at depreciation and maintenance
Synth. fertilizer N	+	+	-
Synth. fertilizer P	+	-	-
Synth. Fertilizer K	+	-	-
Manure N	-	+	-
Manure P	-	-	-
Manure K	-	-	-
Pesticides	+	-	-
Green manure	+	+ (crop residues)	-
Machinery use (all crop operations)	+	+ (fossil fuels)	+
Crop residues N	-	+ (losses post-harvest)	-
Crop residues P, K	-	-	-

Application of manure
In literature, different ways in calculating manure emissions can be found. This is related to the view on manure. In some references(…), manure is considered as a waste of livestock systems and all emissions from both storage and application (energy requirements and nitrous oxide emissions) should be allocated to the livestock system. When manure is applied on grassland or arable land, it (partly) replaces the use of synthetic fertilizers (N, P and K) and, in theory, emissions for the production of synthetic fertilizer can be avoided. These avoided emissions can be withdrawn from the manure emissions. The emissions of the receiving crop do not change, irrespective the use of manure or synthetic fertilizers.
The other approach is to consider manure as a valuable source of nutrients, irrespective the fact that local surpluses occur or that manure has a negative price. In that situation, emissions from storage of manure are allocated to the livestock system and all emissions of the application of manure are allocated to the receiving crop.
The second approach is preferred for a number of reasons. Manure is a very complex carrier of nutrients and organic matter:

- Nitrogen is present in organic and mineral form, the mineral N and part of the organic N is active in the year of application, but the main part of the organic N contributes to long term nitrogen sources. The latter is reflected in the Soil Nitrogen Supply. The synthetic fertiliser application rate should only be corrected for the active N in the year of application.
- The emissions factors of N in manure are based on the sum of organic and mineral N. When emissions are based on avoided synthetic N, the role of the organic N is ignored.
- Phosphorus and Potassium are considered to work in the year of application. But beside those two, a number of trace elements is present in animal manure. These are not accounted for in the first approach.
- Animal manure is also an important source of organic matter, especially on arable land. Soil organic matter can only be maintained by continuous supply of fresh organic matter from crop residues, green manure and animal manure.
- When animal manure is applied at high rates, negative side effects of high N loads can occur. These will be reflected in a high proportion of nitrate leaching and ammonia emission rates and hence in eutrophication and acidification. For that dynamic leaching and volatilization rates should be used.
- Calculating avoided emissions of synthetic fertilizer production requires knowledge about fertilizer recommendations and an agronomic rationale. In many occasions, such recommendations are not known and are probably very diverse. From that point of view it is impossible to consider manure application as a replacement of synthetic fertilizer.

Another reason is related to the scope of the project and the characteristics of landless livestock production systems. To develop a default database for feed raw materials, no particular farms are subject of research. Using the first approach requires information about origin of the applied manure on crops at the beginning of the feed production chain and about the fate of manure of the livestock farm at the end of the chain. This is not the case. In the case of feeding industrial co products or compound feeds, there is no agronomic link between the location of crop production and livestock production.
The formula for calculating N_2O emissions from applied animal manure is based on the IPCC 2006 Guidelines. The general formula is discussed in the next paragraph, in combination with synthetic fertilizer.
Potential emissions of manure application ate the end of the feed production and utilization chain, in the farm phase, are calculated to show the effects of changes in animal's rations on emissions. Effects of mitigation options in feed formulation can be shown.

<u>Collecting data on manure application rates</u>
No detailed information is available about manure application on crops and grassland. Only for Dutch feed production (grass, maize, arable crops), detailed information is available. For other countries and crops within those countries, only occasional data can be found. Therefore, no data on manure application are collected, instead of this a calculation method of Gerber at al. (2010) has been adopted. This methodology estimates manure application rates at a national level on the basis of animal numbers, Tier 1 Nitrogen excretion rates, Nitrogen losses during storage and the area of arable land and grassland. The detailed procedure is described in Appendix 4.

<u>Faeces and urine from grazing</u>
In the case of grazing faeces and urine are deposited in the pasture. The grazing emissions have to be part of the total GHG emissions of livestock products. These depositions and their emissions are incorporated in the calculations of animal manure in the farm phase. It implies that the GHG emissions of fresh grass is based on the nitrogen application rates and the related activities, but not on faeces and urine in the pasture.

<u>Crop residues</u>
Crop residues are a potential source of nitrous oxide emissions. The method of IPCC 2006 Guidelines (IPCC, 2006) has been used for calculating the amount of crop residues, the N in crop residues and the emissions of N from crop residues. A number of crops in the data collection are not covered by a specific set of formula parameters in the IPCC 2006 Guidelines. In that case a second best crop is chosen. The list of crops is in Appendix 5. Detailed information of crop production is collected. When information about crop residues and N in crop residues has been found, a comparison has been made and the calculated figure has been corrected.

<u>Application of synthetic fertilizers</u>
At the application of synthetic fertilizers, three nutrients are distinguished: N, P and K. Emissions of greenhouse gases from the application of phosphorus and potassium are assumed to be nil. The production of fertilizers and the use of equipment for application are discussed in other sections.
The emissions of nitrogen from a number of sources are calculated on the basis of the IPCC 2006 Guidelines (IPCC, 2006).
$N2O\ direct = EF_1 * (F_{SN} + F_{ON}) + EF_2 * (F_{CR} + F_{SON}) + N_2O_{OS} + N_2O_{PRP}$
SN: synthetic nitrogen, crop specific
ON: nitrogen from animal manure (organic and mineral N)
CR: crop residues
SON: will be considered later in LULUC section
OS: organic soils
PRP: pasture, range & paddock; deposition of faeces and urine by grazing cattle.

<u>Cultivation and harvesting</u>
The simulation programs Dairy Wise (Schils et al.., 2007) and MEBOT (Schreuder et al.., 2009) provide detailed information about the activities for ploughing, seedbed preparation, weed control and harvesting. All machines and the required working time per hectare or amount of product are defined in detail. Not all crops are covered by the list in MEBOT. In that case a set of activities of a "next best" crop has been selected. Crops that are harvested by combined harvesters, choppers and lifters have been distinguished.

The method for the calculation of direct and indirect (maintenance and depreciation) emissions for machine use comes from Ecoinvent (Nemecek and Kägi, 2007). The data for the machine life time and Specific Fuel Consumption per hour come partly from Ecoinvent (Nemecek and Kägi, 2007) and partly from internal data of the lant Sciences group (Sukkel, pers. Comm.). Detailed information is in a separate document.
It is known that the scale of agricultural enterprises affects the mechanisation of the farm and might affect the energy requirements for a number of operations. A comparison of normal and large scale farm operations showed a reduction in direct and indirect emissions of 25 %. A correction factor of 0.75 has been defined for soy and corn production at large scale farms in Brazil and the United States of America.

4.4 Calculation of GHG emissions in grass production

Grass is harvested multiple times per year with often predefined yields, manure and synthetic fertilizer applied per cut. This will affect the assessment of the GHG emissions per kg of grass strongly. The land use is expressed in m^2 per kg of grass, which depends on the annual yield. A number of cultivation activities at the start of the growing season and grassland renovation can be considered as general activities and should be partitioned over the annual yield. So, emissions have to be calculated partly on a per cut basis and partly on an annual basis, the land use in m^2 per kg of DM is calculated on an annual basis.
In addition, the quality of fresh grass and conserved grass varies during the growing season. So, animal nutrition and the GHG emissions are affected as well.
The required input data for calculating the GHG emissions of grass are:

- Soil type. At this moment only “normal” soils are considered.
- Annual total N application. From this several parameters are calculated:
    - Fertilizer N applications per cut, based on the fertilizer recommendations scheme (CBGV, 2005).
    - Annual dry matter yield, based on model simulations of DairyWise (Schils et al.., 2007)
- Grazing system. This defines:
    - The amount of organic manure to be applied. In case of grazing faeces and urine are deposited in the pasture directly and have no fertilizer value, manure from the housing period is applied as a fertilizer.
    - The use of grassland also defines the annual fertilizer rate, combinations of grazing and cutting tend to lower annual rates than cutting only (CBGV, 2005).
- Long term grassland management. Is grassland renovated at a regular basis, or is grassland renovation combined with intercropping of one or two growing seasons of maize? Or, in the most extreme situation, is grassland renovation not applied at all?

These issues can be dealt with in a complete grassland simulation, as is done in the model Dairy Wise (Schils et al.., 2007). In the case of the assessment of GHG emissions of grass in the calculation tool, a set of “compound grass rations” (CGR) will be defined, depending on three default types of grassland use. This CGR assures that the grass quality is related to the season and that unrealistic rations will be avoided. Technical details are reported in a separate document.

4.5 Carbon contents in crops and crop products

In GHG emissions assessment, the carbon of plant and animal materials is considered to be part of the short carbon cycle. In livestock production systems, carbon is sequestered in crops, via feed it ends up in undigested faeces and in excreta. In many instances faeces and excreta are collected together in one storage as slurry. In many instances the manure is applied to agricultural land and the carbon is expected to be released to the atmosphere within a few years. So, carbon in crops, animal products and manure is not considered as a carbon sink, nor as an carbon emission source. There is only one exception. Carbon sequestered in soil organic matter is fixed for a very long time and is considered as a carbon sink. This negative emission can partly compensate the emissions of other processes in crop and livestock production.

However, it is desirable to give insight in the carbon flows in crops, co products and compound feeds. For this the carbon content of products should be known. As this is hardly analysed, an approach must be developed to calculate carbon contents of all products. The most feasible way is to calculate carbon contents on the basis of the chemical (Weende) analysis that is present in the CVB list. The four relevant components are crude fibre (CF), crude protein (CP), crude fat (CFat) and other carbohydrates (OC). In formula:
C content = 0.57 * CF + 0.46 * CP + 0.75 * CFat + 0.44 * OC
CF, CP, CFat and OC are expressed in percentages.

A comparison of measured and calculated values is shown in **Table 11**. In most cases a good fit is found, with the exception of wheat grain. The above mentioned formula will be used for calculating carbon contents. It should be noted that relatively little data on carbon contents are available. A further analysis is recommended, focussing on the wide variation in crude fibre and lignin.

Table 11. Carbon contents in dry matter of feed materials from literature and calculated from the Weende analysis

Product	**C (% in DM) literature**	**Calculated**	**References**
Whole plant maize	43,5	45	Loomis & Lafitte, 1987
Wheat straw 1	40,9	46	Porteaus et al.., 2009
Wheat straw 2	43,0	46	Channiwala & Parikh, 2002
Wheat straw 3	45,5	46	Demirbas, 1997
Wheat straw 4	52,6	46	Mackay & Roberts, 1982
Wheat middlings	40,2	39	Tóth et al.., 2006
Wheat grain	43,7	39	Porteaus et al.., 2009
Rice husk	38,5	39	Channiwala & Parikh, 2002
Grass, fresh 1	41,8	45	Jenkinson, 1960
Grass, fresh 2	43,5	45	Jenkinson, 1965
Grass, fresh 3	43,8	45	Rasmussen et al.., 2008
Clover (red and white)	45,1	44	Rasmussen et al.., 2008

4.6 The calculation and allocation of emissions

Cropping systems

Allocation in cultivation systems for feed is relevant for the following situations:

1. Multiple cropping systems:

   Here we apply the method defined in the PAS horticulture specification (draft 2012)

   If inputs in a multiple crop production system benefit all crops but are not specifically assigned to products, the allocation to crops shall be based on crop needs if sufficient information is available otherwise the allocation will take place in relation to the area.

   Application of organic fertilizers (e.g. animal manure, peat products, compost) in agriculture production systems result in GHG emissions that occur within one year and GHG emissions that occur after that year in a new cropping cycle. The delayed emissions are divided over the crops in the crop rotation scheme, planted and harvested in the year of application. In practice it was not possible to collect data on crop rotation systems in the countries for which we needed data

2. Allocation to co-products from plant parts (straw, bagasse, wood)

   If the co-product is used as an energy source in the same production chain, e.g. bagasse in cane sugar production or biogas from fruit bunches in crude palm oil production no upstream GHG are allocated to those products. This means that in the processes further down the production chain the biofuel enters without GHG emissions other than transportation

In all other cases allocation is based on the economic value of the co-products (economic allocation).

a. Economic allocation fractions shall be averaged over at least three years and at maximum five years.

b. Economic allocation shall be conducted on the basis of input /output analysis or on the basis of component value estimation

Mass based and energy content based allocation may be applied as part of a sensitivity analysis

Crop rotations

Most arable crops are grown in a rotation with other crops. This can range from growing the same crop every second year to growing crops every 5 or more years. There are many agronomic reasons for using crop rotations, such as controlling pests and diseases, maintaining soil fertility and soil organic matter levels. A number of activities and inputs are crop specific and emissions related to them can easily be attributed to the crop. Some of the activities and inputs are related to the complete crop rotation, such as application of manure (nutrients active in more than one year) and green manure to maintain soil organic matter levels. Wegener Sleeswijk et al.. (1996) and Blonk (2009) identify a number of crop specific activities and inputs and suggest to allocate on the basis of crop requirements or actual nitrogen uptake by crops. This more detailed approach requires much more data. Not only information of the specific crop is required, but also of the other crops in the rotation. Due to the limited data availability and quality about manure application and crop rotations, the long term nitrogen emissions will be allocated entirely to the crop where the manure has been applied.

Table 12. An overview of the allocation of emissions to the specific crop or on the basis of the areal fraction of the crop in a rotation scheme

Input/activity	Crop specific	Areal fraction	Comments
Synth. fertilizer N	+	-	Active in year of application
Synth. fertilizer P	+	-	
Synth. Fertilizer K	+	-	
Manure N	+	+	N_e fraction is crop specific, N_R is added to long term soil nitrogen supply
Manure P	-	+	Assumed to contribute to soil fertility in general
Manure K	+	-	Highly soluble, active in year of application
Pesticides	+	-	
Green manure	-	+	Including all activities and inputs
Machinery use	+	-	
Crop residues N	+	-	N losses from crop residues are crop specific, N transfer to other crops are not considered, although contributing to long term soil N supply
Crop residues P, K	-	-	Transfer of P and K to other crops not considered.

Table 12 shows an overview whether emissions should be allocated entirely to a crop (crop specific) or are allocated on the basis of their areal fraction. All synthetic fertilizers are active in the year of application and are thus crop specific. Manure N is partly active in the year of application and partly contributing to long term N availability. The fraction of N that is active in the year of application is based on working coefficients of manure in relation to the method of application (Adviesbasis bemesting landbouwgronden, others). In case of manure application for Dutch crops and the availability of detailed information on mineral and organic nitrogen in manure, the working coefficients of Velthof et al. (2010) are used.

Pesticides are completely crop specific, no pesticides are considered to contribute to a long term effect on pests and diseases. Green manure has different functions in the crop rotation. First it contributes to soil organic matter, which is in favour of all crops in the rotation. Second, it captures nitrogen surpluses from the previous crop and acts as a nitrogen transfer to crops for the next growing season. This is important in low input systems. Third, it can be grown as a catch crop to capture nitrogen surpluses, while the transfer function is of limited importance. This is the case in high input systems. It is hard to determine which of the three functions (organic matter, capture and transfer of N) is the most important one. So the allocation of green manure is done on the basis of the frequency of green manure in the whole crop rotation. When green manure is grown every two years, 50 % of the emissions related to inputs, activities, crop residues etc. are allocated to the specific crop.

Calculation of emissions
An overview of the input data for the crop production is shown in Table 13. All inputs are expressed as units per hectare. The first step is to calculate the total emissions for crop production and LULUC:
Emissions cultivation (kg CO2 eq per ha)
= production of inputs * emission factor per input
+ application of N (manure/fertilizer) * emission factor (manure/fertilizer)
+ cultivation (direct/indirect) * emission factor (direct/indirect)
+ storage energy * emission factor energy

Emissions LULUC (kg CO2 eq per ha)
= emissions LU + emissions LUC

After calculating the emissions, the net yield is calculated from the gross yield, corrected for the storage losses.

Net yield (kg/ha)
= yield * ((100 – storage loss)/100)

Finally, the emissions per kg of product are calculated:

Emissions cultivation for a crop product (kg/kg)
= emissions cultivation / net yield

Emissions LULUC for a crop product (kg/kg)
= emissions LULUC / net yield

Table 13. Overview of input and output data of the crop production phase

Crop production, input data	
Production of fertilizers, pesticides	CO2 eq/kg product
Application of fertilizers	Kg/ha
Application of manure N	Kg/ha
Cultivation direct energy	Hours/ha, Fuel use/hour
Cultivation, indirect energy	MJ(energy carrier)/hour
Crop yield	Kg product/ha
Storage loss	% (kg/100 kg product)
Energy use storage	MJ/1000 kg product
Emissions production of fertilizer etc.	Kg CO_2 /kg N,P,K, active ingredient
Emissions fertilizer application	Kg N_2O /kg N
Emissions cultivation	CO_2eq/unit energy type
Emissions LULUC	CO_2eq/hectare
Emissions energy use storage	CO_2eq/MJ energy type
Crop production, output data	
GHG emissions crop products	Grams/kg product (N_2O, CH_4, CO_2)

4.7 Land use and land use change

Land use
Carbon stocks change due to cultivation practices. In general carbon stocks under grassland tend to increase (Conant et al., 2005; Soussana et al.., 2007, 2009) and are affected by stocking densities, nitrogen inputs and grassland renovation (Conant et al.., 2005; Vellinga et al.., 2004). There is a debate whether the carbon sequestration tends to an equilibrium (Conant et al.., 2005 or whether this is a continuing process (Soussana et al.., 2007, 2009). In case of an equilibrium, the carbon sequestration rate will level off on the long term (Figure 7), in case of a continuing process, carbon sequestration rate will remain at a more or less constant level. Model calculations show that it takes many years before the equilibrium is realized. Vellinga et al.. (2004) calculated sequestration rates of

40 kg C per ha of grassland of 200 years old. This sequestration rate is much lower than the 600 - 800 kg reported by Soussana et al.. (2007; 2009). At this moment, the equilibrium approach is the most common in research and will be used as the preferred method.

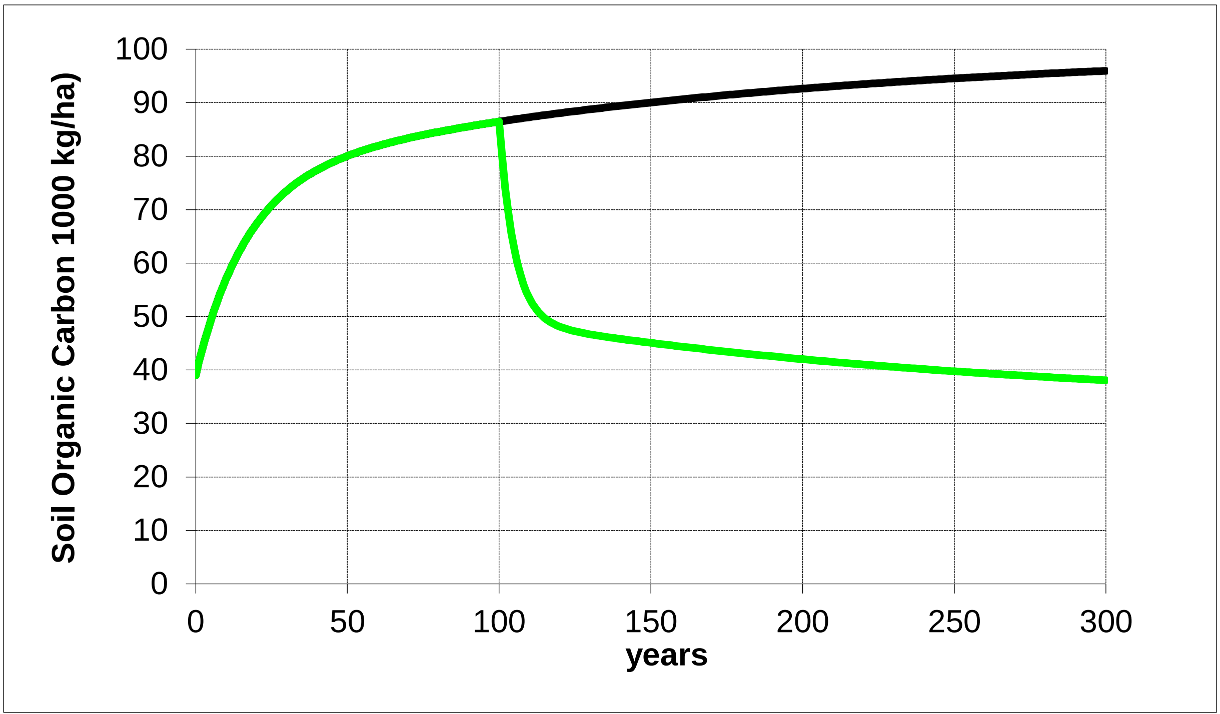


Figure 7. The amount of soil organic carbon under grassland (top line), arable land (bottom line). Arable land starts after a one hundred year grassland period. After 200 years of grassland, sequestration is still 40 kg C per ha per year. After 200 years of arable land, emission of soil carbon is still 30 kg C per ha per year. Calculations based on Vellinga et al.., (2004).

Similar differences in approach can be found under arable conditions. Due to cultivation carbon stocks tend to decrease. The decrease rate, however, is strongly affected by the return of crop residues to the field, the application of organic manure and the tillage intensity. No tillage systems lead to increased soil organic carbon contents. Sukkel (pers. Comm.) found literature indicating losses of soil organic carbon on arable land for a long time. The average carbon loss was about 400 kg per ha per year for conventional agriculture. Leip et al., (2010) base their approach on the work of Soussana et al.. (2007; 2009). Although Leip et al. (2010) assume an ongoing sequestration on grassland, they accept the equilibrium method for carbon losses under arable land. The equilibrium method is supported by Reijneveld et al.. (2009), who found a constant soil organic matter content on arable land in the Netherlands. Vellinga et al.. (2004) calculated carbon losses of 30 kg per ha per year on old arable land (200 years). Sukkel (pers comm) did not find differences in carbon loss or sequestration between European countries.

Another point of debate is the reference level. Leip et al.. (2010) use the natural grassland vegetation as the reference level. Because intensively managed grassland has a higher carbon sequestration rate, land use emissions are negative. Arable land, without sequestration and without net loss of soil carbon in the concept of Leip et al.., (2010), has a (calculated) emission of CO2. In fact this emission is a “not realized sequestration”. So, in this concept, virtual emissions are calculated. We will use the current agricultural land us as a reference level instead of the natural vegetation for two reasons. First, the natural vegetation is not a realistic reference value. Agricultural land use is related to human occupation and we cannot survive without agriculture. Second, the use of natural vegetation as a reference calculates missed sequestration as a carbon loss, as an emission to the atmosphere. Emissions by land use will be calculated on the basis of a long time equilibrium and with the current land use

Accurate figures of land use emissions can be calculated when detailed information is known at field level about land use type, tillage, fertilizer inputs, manure application and type of crop. In case of developing defaults at a national level, such detailed calculations cannot be performed. For grassland, a carbon sequestration rate of 114 kg per ha per year is used for permanent pastures without grassland renovation, with assumed minimum and maximum rates of 0 and 228 kg per ha per year, respectively. In the case of grassland renovation, the sequestration rates are lower (Table 14), especially when grassland renovation is combined with two years of maize cropping in between. In those cases, a similar range of 100 % above and below the value is applied.

Table 14. Changes in carbon stocks for different situations of long term grassland management. Calculations based on Vellinga and Hoving (2011)

Long term grassland management	C stocks at t=0 (kg/ha)	C stocks at t=70 year (kg/ha)	Annual change (kg/ha.year)
No renovation	80,100	88,080	114
Renovation 1/12 year	80,100	83,355	47
Maize 2/12	80,100	73,155	-99

Beside the changes in carbon stocks, grassland renovation and ploughing grassland for maize also affect the emissions of nitrous oxide during the period that the sward is destroyed. For grassland renovation, the period of sward destruction is short, but for maize this period is two years. The nitrous oxide emissions are shown in Table 15.

Table 15. Losses of N, nitrous oxide emissions expressed as N2O-N and CO2 equivalents per hectare per year.

	N-loss due to ploughing (kg/ha)	Total emissions of N2O-N (kg/ha)	Total emissions of CO2eq (kg/ha)	Annual emissions N2O-N (kg/ha.year)	Annual emissions CO2eq (kg/ha.year)
No renovation	0	0	0	0	0
Renovation 1/12 year	141	4.58	2145	0.38	179
Maize 2/12	819	26.62	12466	1.90	890

Emissions from changing carbon stocks, including grassland renovation: (all expressed in kg/ha.year)
Carbon stocks (long term average)
dC stocks = 114 * Norenovation + 47 * Renovation – 99 * Maizegrass
CO2 emission = dC stocks * 44/12
Nitrous oxide (at ploughing, averaged over whole period)
N2O cultivation = (0.38 * Renovation + 1.90 * Maizegrass) * 44/28
CO2q cultivation = N2O emissions * 298
Norenovation, Renovation and Maizegrass can be treated as Booleans.

For arable land, a carbon loss of 30 kg per ha per year is used, with a minimum rate of 0 and a maximum rate of 60 kg per ha per year. The high rates in the range of 600 to more than one thousand kg are related to situations with recent land use change. The fluctuations of soil organic carbon due to arable – ley rotation schemes are considered to be short term carbon changes and are not considered.

A simplified approach for LUC

Many studies have been performed to estimate emissions from land use change. They range from studies directly related to the production of a crop in a specific region to global studies on the expansion of bio fuel production. E.g soy has been subject of many research projects (Cederberg et al.., 2011, Prudencio da Silva et al.., 2010, Gerber et al.., 2010), global studies on biofuels has been studied extensively (Searchinger et al.., 2008; E4Tech, 2009, Hertel et al., 2010). One of the complicating factors in calculating GHG emissions from land use change is the distinction between direct and indirect land use change and the, in part political, discussion about the drivers of land use change. This is illustrated in Figure 8.

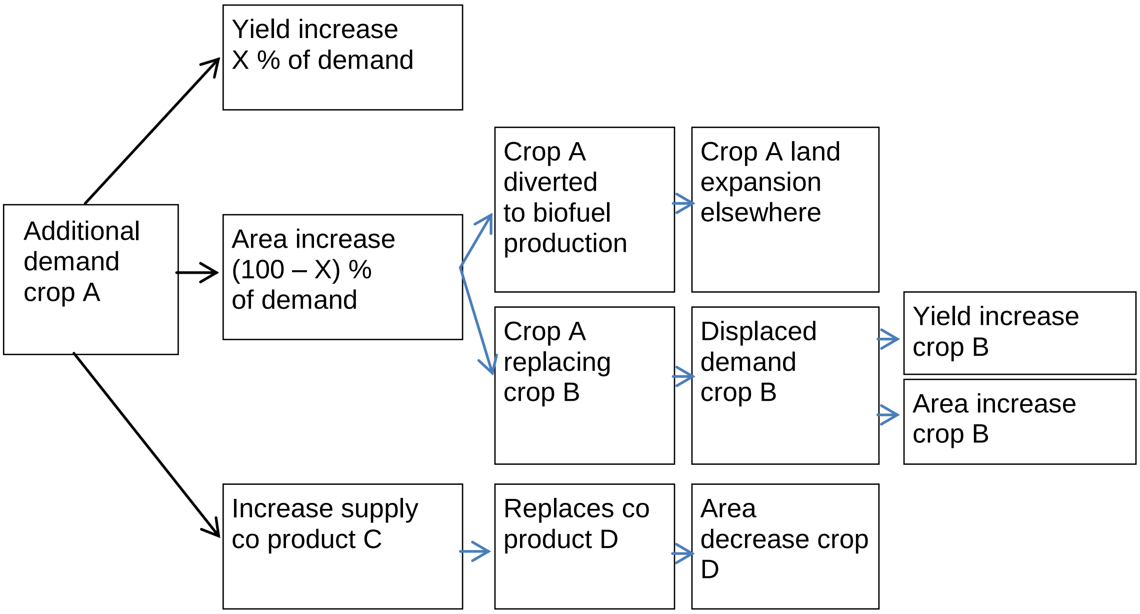


Figure 8. The direct and indirect land use change effects of an increased demand of a crop.

An increased demand of crop A for e.g. biofuel is matched a) by a yield increase and an b) by area increase. The area increase of crop A for biofuel is partly coming from crop A for other purposes and partly from crop land expansion. For another part, the area increase of crop A goes at the expense of crop B. The displaced demand is compensated elsewhere, partly by yield increase and partly by area increase. Another possible effect is that co products of biofuel production can be used as feed and might replace other products. The area decrease is considered as a positive effect. This complex situation of direct and indirect land use change is hard to entangle. It is therefore hardly possible to get reliable figures about replacement factors.
A comparison of a number of studies has been performed and is described in detail in a separate documentation report. The conclusions of this comparison are:

- Calculations of GHG LUC emissions are often very complex and are based on many assumptions, as e.g. the replacement factor, the magnitude of the carbon stocks in different land use types, the incorporation of missing sequestration potential etc.
- Changes in crop areas affect the areas of other crops, within a country, but also between countries and continents. The drivers of direct and indirect land use changes can hardly be separated, due to the many relationships and interdependencies.
- Assessing effects of future scenarios or analysing drivers will not provide a clear conclusion
- On the basis of the complexity of direct and indirect land use change, LUC assessment of single crop is useless
- A simple and robust method is still lacking

An interesting point of view is found in the report: “How Low can you go?” (Audsley et al.., 2009). The method described in Audsley et al.. (2009) is based on the idea that human consumption is the driver and that all agricultural production systems are connected. This is especially the case for market oriented agriculture and to a lesser extent to non-commercial agriculture. From this point of view all land use change emissions (non-agricultural land converting to agricultural land) should be related to the agricultural land itself. This results in a calculated average emission of land use change for every hectare in agricultural use on the globe. For a product based land use change emission, the emission per hectare has to be divided by the yield per hectare.

The calculation scheme is:
Average LUC GHG per ha = Global LUC GHG emissions / global agr. land use
LUC GHG emissions per kg = average LUC GHG per ha / yield per ha

A comparison of a number of studies and the incorporation of nitrous oxide emissions (see Appendix 6) shows an overall average of 5.8 Gt CO_2 equivalents per year, with a minimum value of 3.3. and a maximum of 8.1 Gt. The variation coefficient is 49 %, which is close to the figure of 50 % by Houghton (2003, 2010).
Agricultural land use (grassland, arable land and permanent crops) in the period 2001 – 2009 is 4.9 Gigahectares (10^9 hectares) (FAOstat, 2011). The global average LUC GHG emissions per hectare are 5.8 / 4.9 = 1.18 ton per hectare, with a range of 0.67 to 1.65 ton per hectare.
Land use change emissions of crops depends on the crop yield. Figure 9 gives an impression of the LUC GHG emissions per kg of product with the uncertainty range.

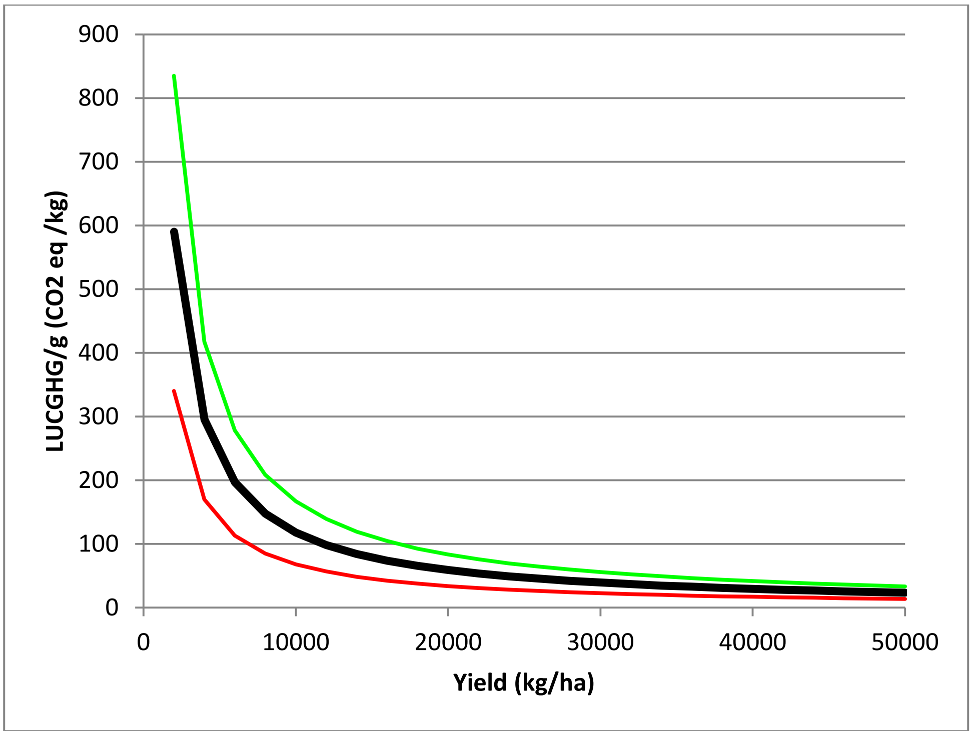


Figure 9. Land use change GHG emissions depending on the crop yield, including the chosen uncertainty range

The method has the advantage of being simple, robust and stabile and the number of assumptions is limited. The approach focusses on the central item of agricultural production: the land use, driven by consumption of a wide range of products. When crop A is grown, there is no room for crop B. The approach prevents a discussion about displacement of crops and interaction between direct and indirect land use change. Every change in production of a crop leads to a change in land use (m^2 per kg of product) and LUC GHG emissions (CO2eq per kg of product). The approach shows efficiency of crop and livestock production: low yields or a bad feed conversion lead to a higher LUC emission.

Although the method is simple, the method also deals with large uncertainties due to uncertainties in estimating global LUC GHG emissions. The approach also does not make any distinction between crops that are expanding due to new developments and crops that don't expand. It is not a cross-sectorial analytical tool for analysing drivers of land use change. It in fact only accounts for the emissions caused by the shift from non-agricultural land to agricultural land and does not account for land use change within agricultural land. Shifts from grassland to arable land e.g. are omitted.

The LUC emissions as calculated will stimulate to increase yields per hectare for every crop, because higher yields will lead to lower LUC (and LU) emissions per kg. Another effect might be the search for high yielding crops at the expense of the low yielding ones. Shifts from one country to another might also be possible. There is always the risk of trade-offs. But also in other approaches, the risk of trade-offs exist. Increased demand for other crops or co-products that are not directly related to land use change can lead to changes in cropped areas and as a consequence to land use change as well. The attributional LCA is never the good tool to explore mitigation options that will affect supply, demand and trade. This holds for every method of LUC calculation.

An advantage of the proposed method is that there is not a strong preference to certain crops due to their calculated LUC emission. Crops are chosen on the basis of their agricultural properties such as yield, quality and response to intensification.
Mitigation options in the calculation tool, should be combined with the condition that the total area of land use should not increase. Neither in Europe nor in other continents.
The intensification might be a risk. But in the GHG emissions calculation, the emissions from cultivation, land use change and land use are shown separately. So, it is possible to see the effects of intensification and see whether this is an improvement or not.

4.8 Data collection

Data requirements
For each crop in each country (see **Table 4**) the data that are needed to calculate the GHG emissions of crops are listed in **Table 16** and **Table 17**.

Table 16. Data questionnaire crop production, inputs, cultivation and other activities.

Product	parameter	Value				Unit
		Mean	SD	Min	Max	
Plant material	amount					kg/ha
Fertilizer	P_2O_5					kg/ha
	K_2O					kg/ha
	N- fertilizer					kg/ha
Lime	lime					kg $CaCO_3$/ha
Manure	manure					kg N/ha
Pesticides	active ingredients					kg/ha
Land use	soil organic matter content					kg/kg
	% peat soils					%

Table 17. Data questionaire crop production, output.

Product name	Parameter	Value				Unit
		Mean	SD	Min	Max	
name product 1	yield					kg/ha
	dry matter content					kg/kg
	price					valuta per unit
name product 2	yield					kg/ha
	dry matter content					kg/kg
	price					valuta per unit
above ground crop residue	N					kg/ha
below ground crop residue	N					kg/ha

Extrapolation of missing data
Introduction
GHG emissions assessment of animal nutrition involves computing Life Cycle Impact Assessments (LCIA) of crops. The LCIA's of crops are computed on the basis of, amongst others, the inputs used during crop production. The underlying project focuses on feed which consists of many different arable crops sourced from many countries around the world.
The number of input parameters and their level of detail required for the LCIA of crops is considerable and parameter values are not always available. An in-depth assessment of each feed ingredient is

therefore not feasible. The goal of this document is to describe a methodology to fill the data gaps with regard to crop production. The described methodology can be used to derive LCIA results for crops.

Methodology
Missing parameter values on crop production can be derived by extrapolation of available values using Modular EXtrapolation of Agricultural LCA (MEXALCA). MEXALCA was developed and described by Roches et al.., 2010, who concluded that the model is valid for the evaluation of the global warming potential of crops. The model consists of two steps. The first step relates to the extrapolation of parameter values and this step will be discussed in this paragraph. The second step relates to the computation of the environmental impact. Underlying project does not use this method to compute the environmental impact of crops and therefore this step is not further discussed methodologically.

The method focuses on geographical extrapolation, in which the input data known for the original country is extrapolated to the target country, for which the data is unknown.
The crop inventory in MEXALCA is divided into nine modules which are known to dominate the environmental impact of crop production. The nine modules distinguished are:

1) Basic cropping operations
2) Variable machinery use
3) Tillage machinery use
4) N mineral fertiliser use
5) P mineral fertiliser use
6) K mineral fertiliser use
7) Pesticide use
8) Irrigation
9) Drying

For extrapolation for the modules variable machinery use, nitrogen, phosphorus and potassium fertiliser use and pesticide use, the yield ratio explicitly occurs, assuming that the farming inputs per hectare are linearly related to the yield ratio. This results in the following equation (Weiler et al.., 2010)

$$\widehat{X_t^c} = X_0^c \cdot \frac{Y_t^c}{Y_0^c} \cdot \sqrt{\frac{ind_t^x}{ind_0^x}} \quad (1)$$

The yield ratio also occurs for extrapolation for the module drying, resulting in the following equation (Weiler et al.., 2010)

$$\widehat{X_t^c} = X_0^c \cdot \frac{Y_t^c}{Y_0^c} \cdot \frac{ind_t^x}{ind_o^x} \quad (2)$$

The following definitions apply:
$\widehat{X_t^c}$ and X_o^c: amount of farming input in the target (t) and original (o) country for the production of crop c (kg N/ha, kg P_2O_5/ha, kg K_2O/ha, kg active ingredient/ha)
Y_t^c and Y_o^c: yields in the target and original country (kg raw product per ha)
ind_t^X and ind_o^X: the agricultural indices in the target and original countries, representing input use intensity

The indices are taken from FAOSTAT. FAOSTAT provides country-specific data on average input use per hectare (e.g. N fertiliser per hectare). These indices are not crop specific, but with the yield ratio between the original and target country, and the input use per hectare for the specific crop in the original country, the input use for the specific crop in the target country can be estimated.

The modules on machinery use and water use do not include the yield ratio. Modules on machinery use apply an intensity index for the level of mechanisation rather than a physical input. Further details on these modules were not provided.

Validation of MEXALCA
The validation of the MEXALCA model is done on the basis of the combined extrapolation step (step 1) and the computation of the global warming potential (step 2). In the underlying project we do not use step 2, since we developed our own method to compute global warming potential of crops. Therefore, the validation as reported by Roches et al.. (2010) is not valid for assessing the extrapolation step. Nevertheless we will provide some validation results here:
MEXALCA is evaluated only for application on commercial and conventional annual crop production systems in developed countries, with the system boundaries set at the farm gate. In a validation of the method, MEXALCA results were compared with Ecoinvent values (Roches et al.., 2010). It was concluded that MEXALCA performs fairly well for the evaluation of the global warming potential, with a Pearson's correlation coefficient of 0.75. The method seems to overestimate the impacts between about 15% and 30%. The method also performed well for the evaluation of ozone formation and energy demand, while it was inaccurate for the spatially dependent impact categories eutrophication and acidification, and found not suitable for impact categories on toxicity.
Roches et al.. (2010) present the sensitivity of the global warming potential to the main farming inputs per kilogramme of wheat, with the sensitivity corresponding to the mean absolute variation of the impact. The impact sensitivity to N fertiliser use and irrigation are highest (39% and 16% respectively), meaning that high quality data on these two inputs is most important. The sensitivity to the other modules is 4% or less, with the lowest sensitivity for K fertiliser use and drying.
Roches et al.. (2010) focuses on geographical extrapolation only. Other types of extrapolation, such as product extrapolation (e.g. from wheat to barley) or technological extrapolation (from conventional to organic) were not explored. The method was also not tested for animal manure application, for reasons of data unavailability.
The MEXALCA model was applied using several modelling simplifications, among which the assumption that environmental characteristics (e.g. soil texture and precipitation) were equal and that all farming inputs are the same across the world. Extrapolation from input data to a target country which highly differs from the original country should therefore be prevented.

Conclusion
MEXALCA is a suitable method to generate missing data on input use and GHG emissions assessment on a multi-country scale. The method allows valid extrapolation of existing data to target countries of which this data is not available. The method should be seen as a complementary approach to the conventional gathering of data. It can be applied in the underlying project to generate the data which is necessary for computing the GHG emissions of animal feed.

4.9 Uncertainty

There will surely be temporal and spatial variability's in the values of each parameter listed in

Table **67** and Table 68. The data series for each parameter however are too small to derive a probability density function for the parameter. In most cases there is just one single value of a parameter available for cultivation of a specific crop in the whole country, for example fertilizer use. In the database of Fertistat (FAOstat), N, P,K fertilizer application rates are provided for a crop in a country with only one value for the application rate of N, one for P and one for K. There is no indication on the most likely value, or on a lower or upper limit. In some cases, more data sources report fertilizer application rates and this may lead to insight into lower and upper limits. In these cases, the Pedigree matrix is helpful in deriving the best estimate and upper and lower limits.
It is beyond questioning that due to spatial variation in soil physical, soil chemical and soil biological conditions, fertilizer use within a country will vary between 2 boundaries: the lower and upper limit. The question however is, which probability density function is most appropriate, and what is a reasonable bandwidth?
For cultivation data uncertainty ranges (and a probability density function) will be assigned to

a) Seed application rates
b) Fertilizer application rates
c) Manure application rates
d) Lime application rates
e) Pesticides application rates
f) Yield
g) Dry matter content (of the crop product)

h) Crop residues

Unless data indicate otherwise, we assumed that the distribution and uncertainty range of these parameters can be described by one of the probability density functions:

1. Normal distribution
2. Uniform distribution

In **Table 18** the default probability density functions and bandwidth of parameters are listed. The choices are underpinned in the remainder of this section.

Table 18. Probability density functions (PDF) and bandwidth (BW) for cultivation parameters

Parameter	In EU countries		In USA		In other countries	
	PDF	BW*	PDF	BW*	PDF	BW*
Seed application rates	Normal	±5%*BE	Normal	±5%*BE	Normal	±5%*BE
Fertilizer application rates	Normal	±10%*BE	Uniform	±40% *BE	Uniform	±40% *BE
Manure application rates	Normal	±10%*BE	Uniform	±40% *BE	Uniform	±40% *BE
Lime application rates**	Uniform	0-800 kg/ha	Uniform	0-800 kg/ha	Uniform	0-800 kg/ha
Pesticides application rates	Uniform	±20%*BE	Uniform	±20%*BE	Uniform	±40%*BE
Yield***	Normal	±2*SD	Normal	±2*SD	Normal	±2*SD
Dry matter content (of the crop product)	Normal	±0.05	Normal	±0.05	Normal	±0.05
Crop residues	Normal	See yield	Normal	See yield	Normal	See yield

* BE = Best estimate

** For lime application rates a Uniform distribution between 0 and 800 kg $CaCO_3$/ha will be applied for every crop in every country, unless reliable data suggest something else

*** SD=Standard deviation; the bandwidth is defined to 4 times the SD

<u>Application rates</u>

The starting point was that a normal distribution is a good choice when it is reasonable to expect that most farmers (in a country) apply the best estimated amounts of seed, fertilizer, manure, lime and pesticides. In other cases, a uniform distribution will be applied to these parameters.

Seed application rates follow a normal distribution rate, with a small variation around the mean. Fertilizer and manure application rates in the EU follow a normal distribution with a small variation around the mean value. Although there is no strong evidence, we assume that the majority of the farmers in EU countries approximately apply the mean value as provided in data sources. We have 3 reasons to expect this:

1. EU legislation restricts the amount of annual fertilizer and manure application rates
2. EU countries and farms are small or medium sized
3. EU farmers are assumed to optimize the fertilizer use in a cost-effective way.

For other countries, we have less insight into the behaviour of farmers. It is assumed that the variation is much larger and there is no preference for a certain value. A uniform distribution is deemed to be a more reasonable choice.

Data about lime application rates were found in only 12 out of 41 crops. Lime application, however, contributes significantly to the GHG-emissions of cultivation. Therefore, lime application rates should not be set to zero by default, since this would underestimate the environmental impact. Thus, it was decided to estimate the lime application rates for the other 29 crops. It is well known that soil type, soil pH, soil organic matter content and the crop of interest determine the optimum lime application rate. Within a country, the variation can be large as well. For instance, lime application rates in the cultivation of sugar beets in the Netherlands varies between 200 and 700 kg $CaCO_3$ per hectare (IRS website). Therefore we decided to apply the uniform distribution with one lower and one upper limit for every crop in every country. For determining the lower and upper limit, we used the information found on application rates for 12 crops. The maximum lime application rate encountered was 1135 kg $CaCO_3$ per hectare, which is applied in the cultivation of groundnuts in the US. The minimum lime application rate was 12,3 kg $CaCO_3$/ha, which is applied in the cultivation of wheat in France. However, zero application cannot be excluded. In most cases no information about lime application rates could be found. The average application rate in our data set is 380 kg $CaCO_3$/ha, the median value is 350 $CaCO_3$/ha. From these figures, we assume that lime application rates in any crop in any country is between 0 and 800 kg $CaCO_3$/ha, following a uniform distribution, unless data about lime application rates are available for a specific crop.

Pesticide application rates depend, among other aspects, on the amount of infestation and diseases. The occurrence of infestation and diseases are highly variable, both temporal and spatial, so there is no central or most likely value. Therefore it was decided that the uniform distribution is the most appropriate, as every application rate between a lower and upper limit has the same probability of occurrence. In most cases we found little information about pesticide application rates, and usually at most a single value was found. This value is considered the best estimate and the lower and upper limits are derived from this best estimate. Since there is legislation about the use of pesticides in EU and US, the bandwidth in these countries may be smaller than in countries where this legislation is absent. Therefore, the bandwidth of pesticide application rates is set to 40% of the mean value in EU-countries and the US, and to 80% in other countries. Pesticide application usually does not have a large contribution to the GHG-emissions of cultivation.

Yield

"Yield", "Dry matter content" and "Crop residues" are assumed to follow a normal distribution. The mean value of the yield in a country is calculated from the average yield in a country in 5 (consecutive) years. The standard deviation is calculated with the same data.

5 Industrial processing

5.1 Reference units

The reference unit that is employed in describing the industrial processing part of animal feed production, is directly related to the output as described in the crop cultivation. The industrial processing is described using 1000 kg input of crop material (the composition of which should be similar to that of the output in the crop cultivation reports). This reference unit is defined as it is directly prior to processing, and field or storage losses should already have been accounted for at this point.

Thus, all energy and auxiliary material inputs are related to the 1000 kg of crop material input, on an 'as is' basis. The energy inputs were either expressed as kWh/1000 kg input for electricity or MJ/1000 kg for fuels (diesel, natural gas, etc.). All auxiliary materials were reported in kg material/1000 kg input.

5.2 System boundaries, inclusion and exclusion of processes

Table 19 gives an overview of inclusion and exclusion of processes regarding the industrial processing phase. Of concern are all processes starting from the moment the crop product enters the industrial processing operation up until the point where the feed raw material is ready for transportation to the feedmill for the production of compound feed material. The transportation between process steps (if applicable) is also included, but will also be treated in a general fashion as explained in chapter 7.

Table 19. Overview of inclusion and exclusion of parts of the industrial processing phase.

Included	Excluded
Processing • Energy use • Chemicals and other raw materials use (if the mass of the input related to the mass of the crop product input exceeds 2%) • Other emissions related to processing if applicable Transportation between processing steps, if applicable • Energy use • Depreciation of transport means	• Emissions of oxidation of biogenic carbon • Capital goods and use of consumables in processing • All activities not directly related to production, such as commutable traffic, etc.

In its simplest form (1 process with simple input/output) the data was gathered using a format as depicted in **Table 20**,**Table 21** and **Table 22** below. This also includes price data for allocation purposes.

Table 20. Mass balance for an example process

Product	Dry matter content (g/kg)	Best estimate value	Error indication*
Input:			
Crop name	850	1000 kg (default)	
Output products:			
Co-product 1	1000	500 kg	2σ = 100
Co-product 2	900	390 kg	2σ = 80

*A normal distribution is assumed

Table 21. Processing input data

Input	Minimum*	Maximum*	Unit
Natural gas	100	200	MJ/tonne input
Electricity	200	400	MJ/tonne input
Hexane	0	1	kg/tonne input

*A uniform distribution is assumed

Table 22. Data for allocation

Product	Mass (kg)	Dry matter content (g/kg)	Price (Euro/kg)	Energy content (MJ/kg)
Co-product 1	500	1000	0.95	37
Co-product 2	390	900	0.17	17

5.3 Allocation for industrial processing

Economic allocation can be performed in several ways. In the CFPAN tool, economic allocation should ideally be done at the unit process of separation and based on the prices of products at the points of separation encountered within the overall process line. In practice however, these intermediate prices are often not available (or the determination is very subjective) and process specific information on energy usage can be scarce. To make the economic allocation feasible in practice a number of simplifications have to be introduced in most cases.

The most straightforward and often-encountered simplification is to apply allocation on the basis of an input/output analysis of the overall factory (i.e. overall input/output process). This means that the total inputs and related GHG emissions (at the operation and upstream) are divided over the products on the basis of their relative contribution in the overall revenue. Under some conditions the input/output analysis on factory level gives a rather good estimate of the economic allocation on unit process level. However, as also described below, the method has some drawbacks if many or important unit processes exist that are related to one of the plant outputs.

An important issue is that the GHG emissions of feed ingredients become dependent on the location of feed specific processes. Some processing steps of feed ingredients can either be done within or outside the factory gate at a different operator (and this is often encountered for the drying of by-products). In those cases the same feed ingredient may have very different GHG emissions levels (up to a factor 10) caused by the great difference in price between an intermediate and a dry feed ingredient (see Ponsioen and Blonk 2010). If a co-product is sold in its wet form the price is slightly above zero (and can also strongly fluctuate), so that hardly any upstream GHG emissions are allocated. If drying takes place within the company the allocated upstream GHG emissions increases according to the extra revenue generated. However, if one looks at the actual inputs of the total system there is only a very small difference in the GHG emissions of internally or externally processing.

Although in principle the allocation of wet by-products can be applied if data is accurate, it can be argued for treating intermediate wet by-products (which are not the main source of revenue for the production facility) as a residue product with an effectively zero value to which no emissions are allocated. A main reason for this is the uncertainty of the price in the low value by-product, which although it is low, can fluctuate strongly while and introduce unnecessary uncertainties. Also, often a large part of the price will actually be solely the cost of transportation. Thus, with this choice, no upstream emissions will be attributed to the wet by-product (or otherwise a by-product considered with an effective off-factory price of zero). If this product is the dried subsequently, all emissions stemming from that particular process will be allocated towards the final feed raw material, regardless of whether it takes place at the same processing facility.

Summarizing all this, we will distinguish three different situations:

1. **Overall input/output based allocation.** The production system that produces the co-products is strongly interrelated, thus always produces the same type of outputs while the processing steps after the separation step have relatively small inputs compared to the joint inputs before separation.
2. **Unit process separation with allocation at each process step.** The production system produces several co-products equally important for the total revenue without a distinct main product in both intermediate and further processed form.
3. **By-product treated as residue.** The production system has a distinct main product(group) and produces by-products both in its low value intermediate (often wet) form optionally further processed into (dry) products.

For each feed raw material an assessment was made to determine which type of allocation was appropriate or feasible. Approach 2, in many cases the preferred option, was not always feasible due to lack of available data (for example in the wet milling of potatoes and wheat). Only for the wet milling of maize enough detailed information was found to be able to perform a step by step allocation along the industrial process. Approach 3 often involves the production of wet by-products which are subsequently dried in a separate step. Table 23 gives an overview of which approach is used for which industry. The subsequent paragraphs explain in more detail how the three approaches are applied, including some specific examples. In some industrial processing examples, both approach 1 and 3 may be applied if multiple types of products originate from the

Table 23. Indication of applied approaches for economic allocation

Approach 1 Input/output analysis of plant	Approach 2 Unit process of separation	Approach 3 Residue by-product
Cassave for animal feed industry	Wet milling of maize	Bread meal and biscuits
Crushing of oil seeds		Cassave starch manufacturing industry
Dry milling		Cheese, casein industry
Rendering of animal products		Citrus pulp
Rendering of fish products		Consumer potato processing industry
Soy protein concentrate production		Dutch fruit and vegetables and their disposals
Sweet potatoes		Ethanol production from maize, wheat, beets
Wet milling of potatoes, wheat		Malt house and brewery
		Sugar industry

<u>Approach 1: Input/output of plant</u>
The data needed for economic allocation on I/O level are simply the data on inputs and outputs of the factory over a certain time period in a steady state of production (**Table 24**).

Table 24. Input and output data for a one step process.

Input	Output
Mass of agricultural product	Mass of Co-products
Dry Matter Content of agricultural product	Dry Matter Content of co-products
Input of energy carriers	Price of co-products
Mass of other raw materials and chemicals that have a material contribution	Gross Energy content of co-products
	Other dry matter being emitted (loss/waste)

In some cases a subsequent processing step is needed, where instead of the agricultural crop another intermediate product enters the industrial processing plant. An example is the production of palm kernel expeller, where in a first step oil palm fresh fruit bunches are processed for their oil with palm kernels as a co-product. These palm kernels are subsequently processed, usually in a separate crushing facility, where palm kernel oil and expeller are produced.

<u>Approach 2: Unit process separated with allocation at each step</u>
Data collection in case of allocation at the unit process of separation within a plant is more specific for which more data are required. For each process step input/output data (including energy usage) is required (Table 25 and **Table 26**). In the case of the latter, only one specific feed material is treated and the characteristics change. For the intermediate products, price data (as well as composition data) need to be derived based on the final products that arise from further processing.

Table 25. The input and output data of a separation unit process.

Input separation unit process	Output separation unit process
Mass of agricultural product	Mass of intermediates
Dry Matter Content of agricultural product	Dry Matter Content of intermediates
Input of energy carriers up to and process included	Derived price and composition data of intermediates
Mass of other raw materials and chemicals that have a material contribution	Other dry matter being emitted (loss/waste)

Table 26. The input and output data of a feed specific process

Input feed specific process	Output feed specific process
Mass of feed co-product from separation process	Mass of feed co-product
Dry Matter Content of co-product	Dry Matter Content of feed raw material
Input of energy carriers in specific process	Price of co-product
Mass of other raw materials and chemicals that have a material contribution	Gross Energy content of co-product

As an example of this approach to allocation, the first step of the wet milling of maize is shown in **Table 27**, followed by the energy requirements specifically for one of the co-products. In this first phase of wet milling, the corn is received and pre-treated (called 'steeping') from which process intermediate wet corn and the precursor for maize solubles (steepwater) arise. The intermediate wet corn subsequently undergoes a number of process step from which, amongst others, maize starch and maize gluten meal are produced. The price and gross energy content of the intermediate outputs are derived (on a dry matter basis) from their values in the final products that are produced from this intermediate. Due to the nature of processing, the intermediate forms are of high moisture content (the exact figures for which are uncertain) and because of this the prices and composition data were expressed on the basis of the dry matter contents.

Table 27. Data on the steeping process in the wet milling of maize

Parameter	Value		Unit		
Inputs	Mass (dm)	Error	DM (g/kg)		
Corn	1000		850		
Energy inputs	Mass (dm)	Error	DM (g/kg)		
natural gas	192	30%	MJ/tonne corn		
electricity from the grid	8.7	30%	kWh/tonne corn		
Outputs	Mass (dm)	Error	DM (g/kg)	Price (€/kg)	GE (MJ/kg)
Steepwater (wet)	65	10%	100	0.18	14.1
Intermediate wet corn (step 1)	935	10%	450	0.37	17.9

After this separation step, steepwater is dewatered and the CVB-listed animal feed raw material of maize solubles is produced (**Table 28**). This is a feed specific process as described in **Table 26**. The intermediate wet corn from this first step subsequently goes through a number of process steps from which a number of other co-products are produced.

Table 28. Data on steepwater dewatering in the wet milling of maize.

Parameter	Value		Unit		
Inputs	Mass (dm)		DM (g/kg)		
Steepwater (wet)	65		10%		
Energy inputs		Error			
natural gas	1192	30%	MJ/tonne corn		
electricity from the grid	7.1	30%	kWh/tonne corn		
Outputs (CVB Name)	Mass		DM (g/kg)	Price (€/kg)	GE (MJ/kg)
Maize Solubles	65	10%	480 0.18		14.1

A potential caveat is the dependence of the intermediate prices on final product prices, which will always be an approximation to the 'true' price of the intermediate products at a separation step. As the definition of this economic price of intermediate products of changing moisture contents is not strictly defined and direct data unlikely, this should be considered an inherent uncertainty in the choice of methodology of allocation.

Approach 3: Zero-value by-product at unit process

In the case of treating the by-product as having zero economic value, the simplest form needs only the final processing step in which the by-product is processed into its final form (**Table 29**). A number of these wet by-products are listed as they are in the CVB animal feed list and in these cases, for economical allocation, no extra input is needed. In the total GHG emission for this feed raw material, only the final transportation is taken into account. Output information on the energy content and price is not needed as all energy inputs gathered are attributed to one product (though in the industrial processing LCI reports they will usually be included for completeness).

Table 29. The input and output data in the case of a process where the co product has zero economic value.

Input for final processing of by-product (price = 0)	Output
Mass of intermediate residue by-product	Mass of co-product
Dry Matter Content of intermediate residue by-product	Dry Matter Content of co-product
Input of energy carriers	Other dry matter being emitted (loss/waste)
Mass of other raw materials and chemicals that have a material contribution	

5.4 Data collection process

Procedure

Based on the processes related to the animal feed raw materials as listed by the CVB and their countries of origin (see chapter 3), data was sought for each industrial process. Processing data was listed for specific countries when detailed information was available. In most cases, however, data availability was limited a single value either representing a country or region was adopted for a process.

Dealing with data gaps

When no direct data was available for an industrial processes estimates needed to made in order to fill in the data gaps. For each report on industrial processing where this was necessary, the assumptions arrived are described (and obviously the uncertainty ranges reflect the fact that assumptions have been made). Two important approximations that are used multiple times are described below, in order to give an insight into the process of approximations made in the sub reports.

Crushing of oilseeds

In the industrial process of oilseed crushing, vegetable oil is retrieved from oil-rich seeds. The resulting products are crude vegetable oil and resulting meal or expeller which is used as animal feed. Many life cycle related studies on the subject of oilseed crushing can be found in the public literature, mainly because of the interest on oilseeds in the production of biodiesel from the oil they contain. However, especially for the less important seeds in this area (for example safflower seed) little information is available on the oil crushing process. Besides this, since the focus of most studies is on the final production of biodiesel, information for the crushing step only is not always available.

In oilseed crushing, two main methods are prevalent: mechanical pressing and solvent extraction. From literature it is known that mechanical (or cold) pressing is usually able to extract around 75% of the oil, while the more modern and efficient solvent extraction (employing hexane which dissolves the oil) extracts up to 98% of the oil contained in the seed. Using these numbers and the (usually available) oil contents of the seeds, an approximate mass balance can be constructed for these processes when no such mass balance is available from literature sources. The mass balances that result from this approach are deemed quite accurate, as existing data can be reproduced within an acceptable error range.

For the energy use required during processing, approximations are based on available data from rapeseed crushing. Expressing these energy inputs as a function of the final oil production (the most valuable output of the process) gives an indication of the energy requirements for a particular oil seed when its oil yield is known (or determined from the approach above). This is a more rough approximation than the mass balance construction, as higher uncertainties arise in the assumption of expressing the energy requirements per amount of oil produced.

<u>Drying of wet by-products</u>

The energy requirements for drying wet by-products, which can depend on the drying method applicable to a certain type of foodstuff, are not always directly available from literature sources. For example, in some cases high temperature drying can be preceded by a mechanical pressing step in which water is removed in an a far more energy efficient method compared to high temperature drying. This reduced the amount of water which needs to be evaporated.

For the approximation of the energy requirements for drying, usually energy requirements were adopted based on literature sources. Roe (2003) describes a number of different drying options and ranges of energy usage in the food industry, ranging from 3000 to 6000 MJ/ton water evaporated. This range relates to thermal efficiencies from 85 to 35 percent. Although higher efficiencies might be achieved by employing heat recovery methods, these were not assumed to be utilized unless sources indicated otherwise.

5.5 Collection of price data

<u>Definition of prices and applied price data</u>

For economic allocation off factory prices are needed (ILCD 2010). The search for off-factory prices raises the following difficulties:

1. With some exceptions, off-factory prices of commodities are difficult to find in the public domain, because these prices are established through individual negotiations between buyers and sellers, often through brokers and other middlemen firms.
2. The prices found in the public domain are mainly prices
   a. to be paid in harbours (FOB or CIF) or
   b. prices after transport from the producing factory to another factory, the latter sometimes being the feed mill or the farm.

   There are several categories of prices found in the different databases, examples of which are:
   a. FOB (free on board) is the price which includes the basis costs of manufacturing the products as well as inland transport when the goods is delivered from factory to harbour. FOB price does not cover the cost after the goods leaves the departing sea or airport. Therefore in a price list, the seller must indicate the departing port if the offered price is a FOB based price. For instance, if goods depart from Malaysia, the FOB price is printed FOB Malaysia.
   b. CIF (Costs, Insurance and Freight) is the price which includes FOB price, freight charged from the departing to the destination port as well as the relevant insurance fees. The destination port is indicated in the price e.g. “Soybeans, US,cif Rott” refers to soybeans from the US at the harbour in Rotterdam, including transport and insurance costs.
   c. C&F price include FOB price and freight charge from the departing to the destination port. So, C&F prices do not include an insurance fee.
3. Data on prices often do not cover the full pallet of co-products: sometimes prices of one or more co-products are missing, or sometimes prices in a specific country are missing.
4. Different sources publish prices in different currencies

We have concluded from this (among other considerations) that a general correction on prices published in the public domain for transport and insurance costs should be avoided. Nor correction with a percentage neither a correction with an amount per ton.km leads to a reliable approach of off-factory prices, due to the huge variation in costs and travel distances. It is very likely that every possible attempt at correction towards true off-factory prices introduces an unknown error. Therefore we suggest that it is better to use the original, uncorrected prices. This also leads to uncertainties about the economic allocation factors, which should be taken into account. It should be taken into account that the less the product has travelled, the better the price represents the off-factory price.

Price data collection procedure
For products that are imported from countries overseas, the use of export prices (FOB) is preferred above CIF prices. If export prices are not available, import prices must be used that carry the least transport costs.
For many products, processing is done in more than one country. If available, country specific prices will be used to calculate off factory-prices. If country specific prices are not available, the ratio of prices in another country will be used as starting point to calculate off factory prices.
Conversion from one to another currency is done by taking the annually averaged exchange rate. For each currency the exchange rate at the first of the month is used to calculate an average exchange rate for each year. In Appendix 2 the calculated exchange rates for each year between 2005 and 2009 are presented.
Whenever possible, average prices over the most recent five year period will be used (see also section 5.6 on dealing with price fluctuations).

Sources for price data
Public available prices are mainly obtained from the next sources.

1. **FAOstat**
   The prices used are export values per commodity and per country. The prices are computed by dividing the total value of the commodity exported divided by the quantity. The export values are free on board values (FOB). The FOB-type values include the transaction value of the goods and the value of services performed to deliver goods to the border of the exporting country. FOB does not include cost of transport (e.g. shipping), cost of insurances and VAT (United Nations, 1998).
2. **Eurostat**
   The prices used are export values per commodity and per country. The prices are computed by dividing the total value of the commodity exported divided by the quantity. The export values are free on board values (FOB). The FOB-type values include the transaction value of the goods and the value of services performed to deliver goods to the border of the exporting country. FOB does not include cost of transport (e.g. shipping), cost of insurances and VAT (European Communities, 2006).
3. **Schothorst**
   Prices of Schothorst feed research are comparable with the LEI prices at the farm gate. The prices are including VAT and are assumed to be a price of a wholesale company in the middle of the Netherlands. The price is including VAT, storage, insurance and costs of transport to the wholesale company. Both the cost of transport to the feed mill or farm and the profit for the wholesale company are not included.
4. **Agricultural Electronic Bulletin Board Missouri University**
   Missouri University publishes, and regularly updates, current price data on a wide range of animal feed ingredients. Although this source does not provide yearly average prices, it can still give an indication or comparison in some cases.
5. **LEI/Binternet**
   Prices of product that are purchased from abroad (e.g. citruspulp) are defined as wholesale prices. This is the price a product has the moment available in the wholesale (assumed to be in the middle of the Netherlands). VAT is excluded. Cost of transport, stocking, insurance and so on, are included up till the product leaves the wholesale. (LEI, agrarische prijzen monitor. 2011). So, further costs relating to transporting the (compounded) feed to the farm are excluded. Prices which are purchased on the domestic market (e.g. potato press fibers, potato starch, wet beet pulp, potato steam rinds) are the prices a farmer pays for the product. This price is the price including VAT, storage, insurance and transport costs. (LEI, agrarische prijzen monitor. 2011)
6. **Boerderij.nl**
   See LEI/Binternet.
7. **USDA**
   On a number of feed ingredients, prices are available via the USDA either via their database or reports.
8. **Oil world**

Oil world presents prices of oilseeds, the respective oils and oilmeals, palm oil and fish oil. The prices used are world market prices in US $/ton per commodity and per country. The values are generally FOB values (Free on board), or CIF values (Costst, Insurance and Freight), excluding import duty and VAT.

5.6 Dealing with uncertainty

<u>Fluctuations in mass balance data</u>
Mass balances of processing industry of agricultural products may fluctuate a little through variations in the composition of the raw material. These variations are mainly caused by climate conditions. Good or bad harvests differ locally. This means that the origin of provided raw materials is not always the same or according to the same contribution.
The inputs of energy carries and other raw materials/chemicals per unit output is also dependent on the capacity utilization of a plant, which may also fluctuate through the years. Moreover the efficiency of operations is affected by maintenance activities and incidents.
All together the inputs per unit output may vary for over the years while there are no actual changes in the operation itself. For the purpose of drawing up averages these fluctuations are not taken into account because they only have a small impact on the total variation in average GHG emission data of feed raw materials (see section 4.6).

<u>Estimating uncertainty ranges</u>
In most cases, not enough data was encountered to get a direct estimate (in the form of averages and standard deviations) on the range of values for either mass balance or energy use for a particular process. Based on the available data a choice was usually made for the 'best' value, with an indication for either a standard deviation or upper/lower bounds. The type of uncertainty distributions have been discussed in chapter three: normal, lognormal, triangular, and uniform. The type of uncertainty distribution is independently chosen for each parameter and depends on the availability of data (see also chapter 3.8 on the uncertainty distribution types). In the case of processing energy use, usually a lognormal distribution was chosen, as one would sooner expect a tailing off of these values into the higher regions.
During data collection, pedigree scoring was applied for the parameters whenever possible. These score were subsequently used to choose a best estimate value (or minimum, maximum), but were also used to estimate the uncertainty probability range surrounding the best estimate. Although the pedigree matrix is applied in Ecoinvent in a quantitative fashion to arrive at distribution factors for the lognormal distribution, we have not chosen to do this in such a rigorous fashion. One reason for this is that this quantitative method does not apply to the triangular or normal distribution (see also chapter 3.8). However, the pedigree matrix can give some basis for estimating the distribution range, as is exemplified in the next section.
Uncertainty involving technical correlation plays a strong role in processing and when data was estimated from other (but related) processes this was taken into account within the uncertainty assessment. From the Ecoinvent uncertainty pedigree matrix, the following definitions are applied for the scores for the various uncertainty levels for technical processes (**Table 30**). Here, the indicated uncertainty factor is related to the square of the geometric standard deviation, where a score of for example 1.2 is roughly related to a plus-or-minus 20% uncertainty. For this 10% can be added when the data is either from a different region or if the source is considered to be old (or both).

Table 30. The default uncertainty factors in relationship with the pedigree matrix results/

Indicator score	1	2	3	4	5
Further technical correlation	Data from enterprises, processes and materials under study.	Data from identical technology but from different enterprises.	Data from processes and materials under study but from different technology.	Data on related processes or materials.	Data on related processes on laboratory scale *or* from different technology.
Default uncertainty factor*	1	1.1	1.2	1.5	2

* factor contributing to the square of the geometric standard deviation in a lognormal distribution.

<u>Dealing with price fluctuations (five year average)</u>

Economic allocation factors are revenue fractions in each co-product of the revenue per unit of ingoing product. The mass balance (kg co-product per kg ingoing product) is therefore an important factor in calculating the economic allocation factors, and it is relatively constant over time. Prices, on the other hand, can fluctuate considerably. To reduce the effect of price fluctuations, the economic allocation factor can best be calculated from average prices over a certain period. Based on tentative analysis, a five year period is long enough to filter out fluctuations, but short enough to recognize shifts. This can be shown in yearly and five yearly prices for rapeseed and the resulting economic allocation factors (Figure 10).

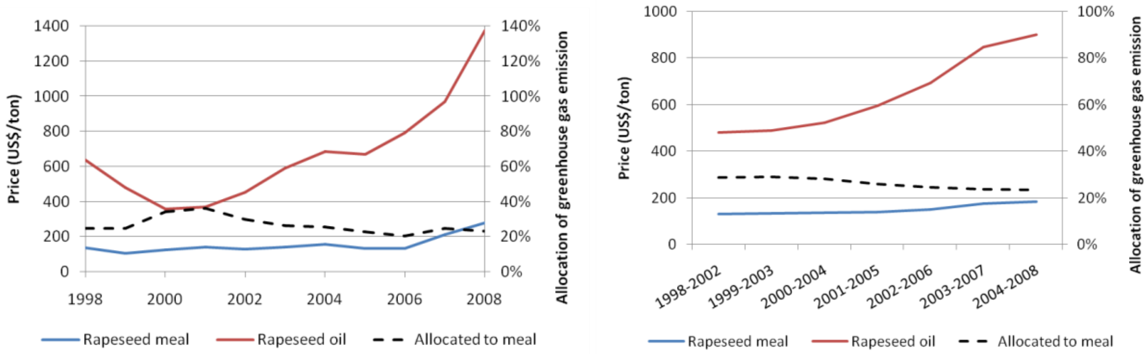


Figure 10. Economic allocation of rapeseed based on yearly (left) and five yearly (right) average commodity prices (Hamburg, prices for meal and Dutch FOB prices for oil, source: FAO prices

Using five-year average prices of soybean oil and meal and sunflower oil and meal results in fairly constant economic allocation factors (Figure 11). It must be emphasized that in these examples the FOB or CIF prices were not corrected for transport costs, which would make the allocation factors for meals in these examples a few per cent lower[2].

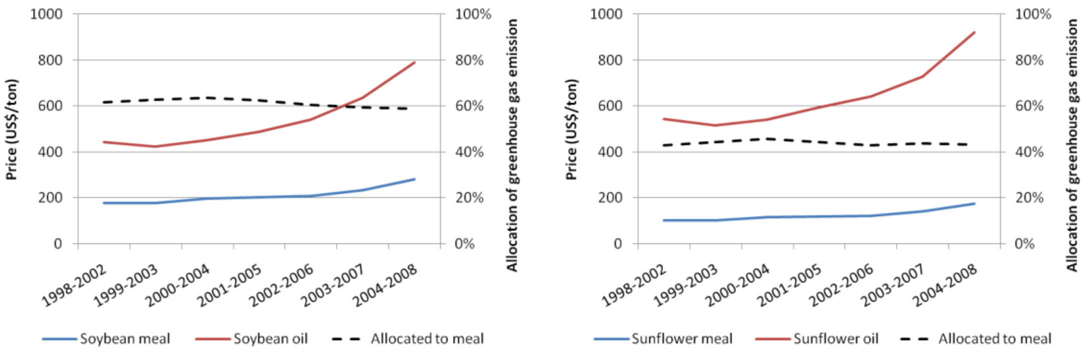


Figure 11. Economic allocation based on five-yearly average commodity prices (Hamburg, prices for meal and Dutch FOB prices for oil, source: FAO prices)

Figure 11 considering the above, average prices over the most recent five year period will be used whenever possible. Please not that price fluctuations, although obviously important, are not dealt with using the Monte Carlo calculations, see also chapter 3.8.

[2] The allocation fraction of meal is lower when calculated with ex-mill prices than with FOB or CIF prices (which include transport), because the ex-mill prices for meal are lower than those for oil, while transport costs are about the same for both.

6 Animal nutrition and farm

6.1 The farm

Figure 12 shows the structure of the nutrition and farm phase of the whole feed production and utilization chain in livestock production systems. The feed can be present in different forms. Roughage production on the farm itself is usual on dairy farms, additional to it co products from industry and compound feeds are bought externally. On monogastric farms and in the case of veal production almost all feed is in the form of co products and compound feeds.

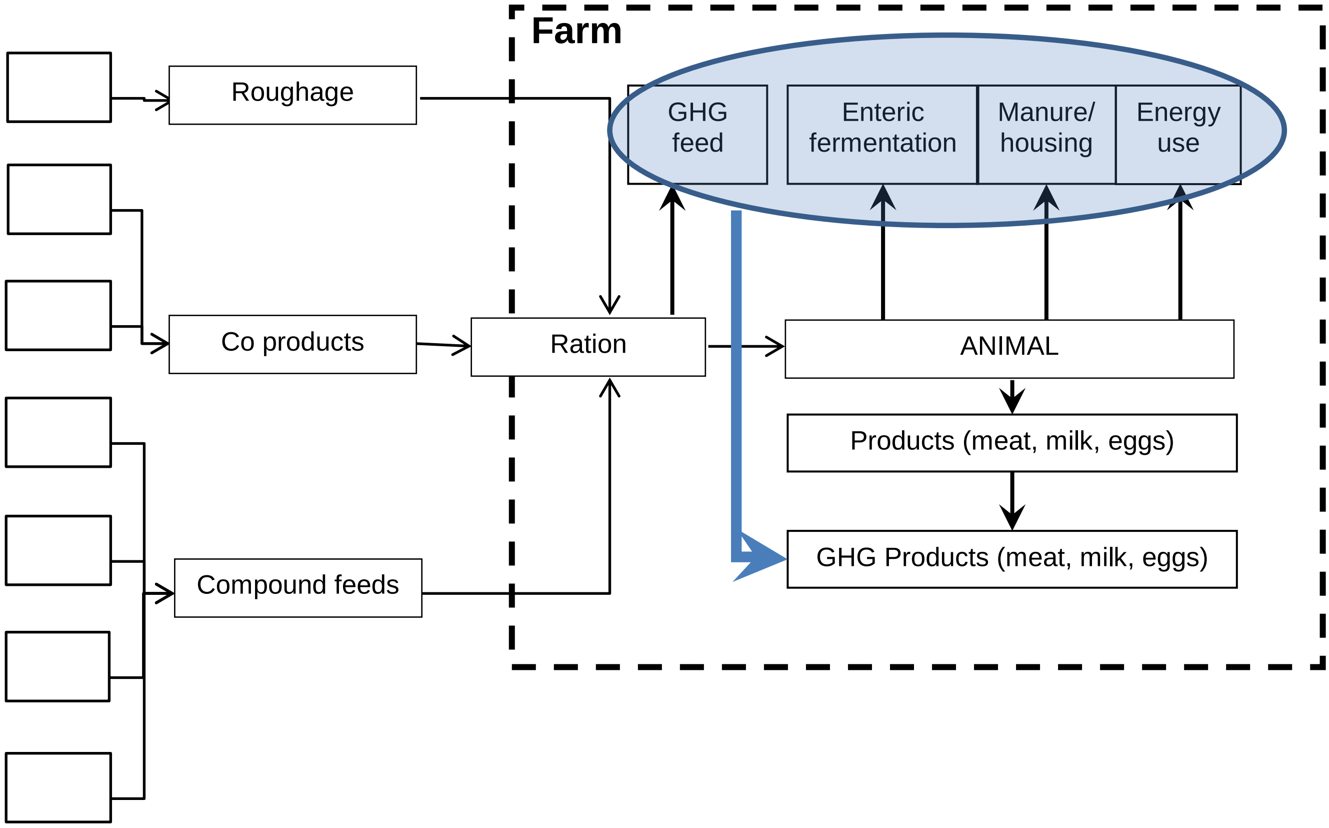


Figure 12. Simplified scheme of the animal nutrition and farm phase of the feed production and utilization chain in livestock production systems

All feed components produced on the farm or entering the farm as an input have embedded GHG emissions, based on their upstream history. Emissions from crop production, industrial processing, compound feed production and transport between these phases are incorporated in these embedded GHG emissions.
The ration is composed of the various components and depends on the animal type and the production goal. The nutritional quality of the feed components is based on the default values of the Dutch feed list of the “Centraal Veevoeder Bureau” (CVB-list). Digestibility, energy contents, protein contents and minerals are in this list. An average nutritional quality of the feed is calculated as a weighted average of all feed components.
The nutritional models of the animals simulate feed intake and calculate growth rates of young animals and production rates of milk and eggs for dairy cows and laying hens, respectively. The models will be discussed in separate paragraphs.

<u>Manure “production”, housing, storage and emissions</u>
Organic matter in animal manure is calculated from feed intake and digestibility of organic matter, the excretion of the nutrients N and P is based on the difference between intake via feed and retention in growing tissue, milk and eggs. The partitioning of N over organic and mineral nitrogen in excreta is

based on the digestibility of the crude protein in the feed. The mineral N is excreted as Total Ammonia Nitrogen (TAN), based on Velthof et al.. (2010).
Nitrogen losses occur during temporary presence of manure in barns and during storage and in the case of faeces and urine depositions of grazing cattle. Nitrous oxide emissions can be separated in direct and indirect emissions and are calculated with the formulas of the IPCC Guidelines 2006 (IPCC, 2006) with the formulas:

Direct - N2O manure = EF * manure-N * 44/28

where:
EF = the emission factor for manure (see table 31)
manure–N originates from nutritional models
44/28 conversion from N_2O-N to N_2O

Table 31. Direct emission factors for nitrous oxide in manure storage. Source IPCC (2006)

	EF (kg N_2O-N/kg N)
Liquid manure	0.002
Solid manure	0.01
Poultry manure	0.001
Grazing	0.02

Indirect N2O – manure = Gasfraction * EF_I

where:

EF_I = the emission factor for indirect emission of nitrous oxide via NH_3 and NO_x. The EF is 0.01 for all situations.
Gasfraction = the fraction of volatilization of N during housing and storage (**Table 32**).

Table 32. Ammonia volatilization as percentage of TAN excretion during housing and storage.

	Liquid manure	Solid manure
Dairy cows, housing period	10.2	10.5
Dairy cows, housed during grazing season	12.4	33.2
Young stock female < 2 year	11.2	11.7
Young stock male	11.7	11.7
White veal	25.8	
Rosé veal	11.9	
Fattening pigs	20.5	
Gilts	22.5	
Sows	19.7	19.7
Layers < 18 weeks	8.98	22.5
Layers > 18 weeks	13.6	16
Broilers		19.5

Note:
The Gasfraction of animal manure is based on the excretion of TAN (Velthof et al.., 2010) and ammonia volatilization during housing and storage (Velthof et al.., 2010) in the Netherlands. IPCC is not used in this case, because the farm emissions are based on Dutch default conditions.
Emissions of application of manure are discussed in chapter 4, at the crop production. However, potential emissions of manure application are calculated to be able to show potential effects of changes in protein contents of rations.

Another important source of emissions is methane. Emissions are calculated at the Tier 2 level of the IPCC 2006 Guidelines (IPCC, 2006), using specific emission factors for the Dutch situation (van der Maas et al.., 2011).

CH_4 manure = EF * manure amount

where:
manure amount is calculated from the nutritional models and can be separated for housing and grazing periods.
EF = OM * B_0 * MCF

where:
OM = organic matter calculated from manure production (Dry matter) and a per animal type default organic matter content (CBS, 2010)
B_0 = potential methane production
MCF = methane conversion factor

The Dutch National Inventory Report 2011 (van der Maas et al.., 2011) uses specific values for Dutch conditions. These are shown in Table 33.

Table 33. Values for the Methane Conversion Factor (MCF) and B_o for different animal types as used in the calculation tool.

Animal category	Manure	Remark	MCF	B_0 m^3/kg OS
Young stock female, < 1 yr	Liquid manure	Confined	0,17	0,25
Young stock male, < 1yr	Liquid manure	Confined	0,17	0,25
Young stock female 1-2 yr	Liquid manure	Confined	0,17	0,25
Young stock male 1-2 yr	Liquid manure	Confined	0,17	0,25
Young stock female > 2yr	Liquid manure	Confined	0,17	0,25
Dairy cows	Liquid manure	Confined	0,17	0,25
Bulls	Liquid manure	Confined	0,17	0,25
Veal calves (rosé)	Liquid manure	Confined	0,14	0,25
Veal calves (white)	Liquid manure	Confined	0,14	0,25
Other cattle	Liquid manure	Confined	0,17	0,25
Suckler cows	Solid manure	Confined	0,17	0,25
Young stock female, < 1 yr	Liquid manure	Pasture	0,01	0,25
Young stock male, < 1yr	Liquid manure	Pasture	0,01	0,25
Young stock female > 2yr	Liquid manure	Pasture	0,01	0,25
Dairy cows	Liquid manure	Pasture	0,01	0,25
Other cattle	Liquid manure	Pasture	0,01	0,25
Fattening pigs	Liquid manure		0,39	0,34
Gilts	Liquid manure		0,39	0,34
Sows	Liquid manure		0,39	0,34
Young boars	Liquid manure		0,39	0,34
Boars	Liquid manure		0,39	0,34
Broilers	Solid manure		0,015	0,34
Broiler parents <18 wk	Solid manure		0,015	0,34
Broiler parents >18 wk	Solid manure		0,015	0,34
Layers < 18 weken	Liquid manure		0,39	0,34
Layers < 18 weken	Solid manure		0,015	0,34
Layers > 18 weken	Liquid manure		0,39	0,34
Layers> 18 weken	Solid manure		0,015	0,34

<u>Enteric fermentation</u>
Enteric fermentation is calculated at Tier 3 level, using the mechanistic rumen simulation model of Bannink/Dijkstra (Bannink et al.., 2008; 2010). This model is a dynamic simulation of rumen fermentation processes and is used in national reporting of greenhouse gas emissions (van der Maas, 2011). The methane production per kg of feed depends on feed characteristics and the interaction of different feed components in the rumen. Because a dynamic simulation is not feasible in the

calculation tool, separate model simulations have been used with different levels of a wide range of feed components, resulting in a set of component specific methane emissions. The set of specific methane emission factors is added to the model database. The methane emission factor EF-CH_4 at the level of the ruminant's ration is calculated as a weighted average of the specific emission factors and the fraction of the feed components in the ration. This approach implies that changes in the ruminant's ration not only affects the embedded GHG emissions, but also the emission of methane from rumen fermentation.

In formula:
CH_4 enteric fermentation = feed intake * EF(ration)-CH_4

Where:
EF-$CH_4 = \sum(F_i * EF_i) / \sum F_i$
Methane from fermentation processes in monogastrics is much lower. Default values at animal levels are used.

<u>Energy use</u>
Energy is used on the farm for a wide range of activities, such heating and cooling, light, ventilation, milking, feeding, manure transport from barn to storage. Energy requirements for farms are based on accountancy data of real farms(KWIN, 2011), barn type and feeding management. They are expressed in MJ per animal per year or MJ per farm unit per animal.
Emission factors for the used energy sources are defined in chapter 8.

6.2 Cattle nutrition

A novel model has been used (Zom et al.., 2012a, 2012b) to predict voluntary dry matter intake of dairy cows, based on feed and animal characteristics. Contrary to many other often used models, this does not include calculation of requirements, based on animal performance (milk yield, bodyweight) to predict feed intake. The model is robust and can be applied to various diets and feeding management situations in lactating HF cows. An evaluation of the model (Zom et al.., 2012) shows good results. Dry matter intake is predicted from feed and animal characteristics. The feed chemical composition and digestibility can be related to feed degradation, bulk volume, intake rate, palatability and other factors influencing feed intake. The data of standard feed analysis are used to estimate the satiety value of numerous commonly used feeds and forages. The satiety value is the measure of the extent to which a feed limits intake. The cows' ability to process the intake-limiting satiety value-units is expressed as the feed intake capacity, which is predicted from parity, days in milk and days of pregnancy which are indicators of the size and physiological state of the cow. With the model, feed intake can be predicted using a limited number of easy-to-measure inputs that are available on commercial farms.

6.3 Animal nutrition growing-finishing pigs

This model allows the user to simulate the production performances of a growing-finishing pig in the range from weaning to 150 kg. With respect to the carbon footprint project, the main aim of this model is to analyse nutrient utilisation for characterised pig types, and to evaluate the effects of using different nutritional strategies on nutrient utilisation, performance, carcass characteristics, faeces production and composition, and volatile emissions from the faeces. The simulation of the pig growth and carcass characteristics are based on the Inraporc model, as described by Van Milgen et al.. (2008). This model is integrated with the MESPRO model, which estimates the amount and composition of faeces from fattening pigs (Aarnink et al.., 1992). The total nitrogen excretion (TAN) was calculated according to Velthof et al.. (2009).

6.3.1 Performance growing-finishing pigs

As model parameters related to feed intake and growth potential are adjusted by the model user, growth (in an absolute sense) is not predicted. The model is based on the transformation of dietary nutrients to body protein and lipid, which are then used to predict body weight, lean body mass and backfat thickness. The representation of nutrient utilisation is mostly based on concepts used in net energy and ileal protein systems. Driving forces of the model include feed intake, the partitioning of energy between protein and lipid deposition, and the availability of dietary protein and amino acids. The model user has to characterise the pig in a situation where it is capable of expressing its potential (in terms of feed intake, protein deposition and lipid deposition) under practical farm conditions. These conditions must be so that there are no identified constraints (e.g., heat stress or disease) that may limit the pig in expressing its potential. Based on this characterisation of the pig, the model allows analysing the way nutrients are used for different functions, and to predict the consequences of using different nutritional scenarios (e.g., the effect of diet composition or a feed restriction on performance). Feed intake is one of the major driving forces in the model and the uptake of faecal or ileal digestible nutrients is taken as a starting point (user input). The metabolic utilisation of nutrients is largely based on classical concepts of energy and amino acid utilisation. Model inputs include the intake of ileal digestible protein, fat, starch, sugars, and NSP. Part of the digestible protein fraction will be deposited as body protein (PD, g/d). The remainder will be deaminated so that the carbon-chain can be used for other energetic purposes. Excess protein, fat, starch, sugars and NSP are converted to NE equivalents, by constant conversion of EW * 8.8 MJ/kg The NE supply from different nutrients are pooled together and is used to provide energy for different support functions (maintenance, physical activity, and the cost of protein deposition). The remainder of this energy will be deposited as lipid (LD, g/d). The PD and LD cumulate in two compartments of protein (P, kg) and lipid (L, kg) mass. An overview of the nutrient partitioning of the model is shown in Figure 13. A detailed description of all the calculations is provided in the paper of Van Milgen et al.. (2008).

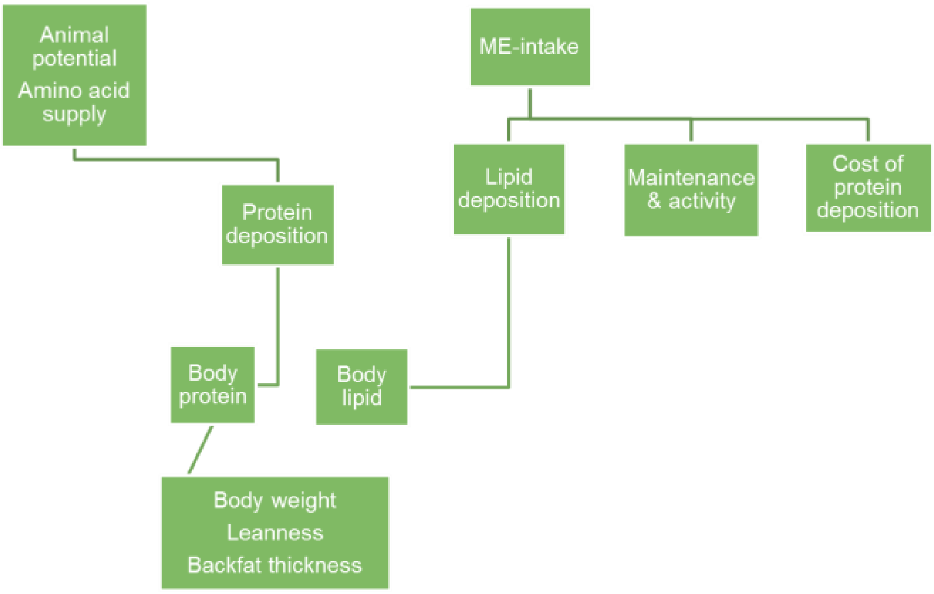


Figure 13. Nutrient partitioning in the growing-finishing pig model

6.3.2 Faeces production and composition growing-finishing pigs

Water intake is calculated on a daily base as follows:
Water intake = (feed intake * Water : feed ratio) + (feed intake * moisture content of feed).

The amount of water excreted is estimated as follows:
Water excretion = water intake – water retention in the animal – water evaporated by the animal + the amount of formed oxidation water.

Water retention is calculated by subtracting protein, fat and ash retention from the growth.

Deviant from the MESPRO model (Aarnink et al.., 1992), water evaporation is calculated according to the BEZOVA model (Sterrenburg and Van Ouwerkerk, 1986). Evaporation is determined by the body surface of the pigs and the ambient temperature, whereas body wetness is also taken into account.

Oxidation of carbohydrates, fat and protein result in the production of carbon dioxide and water, whereas degradation of protein also results in formation of urea. Oxidation of 1 kg of carbohydrate, fat or protein results in 0.556, 1.071 and 0.396 kg of water, respectively.

Dry matter excreted is calculated as follows:
Dry matter excretion = organic matter intake (1 – digestibility coefficient of organic matter) + amount of organic matter in the urine + ash intake – ash retention.

The amount of organic matter in the urine can be calculated by multiplying N-excretion in urine (= N digested – N retained) by the factor 60/28 (conversion N to urea). N-excretion in urine is assumed to be similar with TAN.
DM content of faeces (%) is calculated by DM excretion : water excretion * 100.

6.4 Animal model reproductive sows

The sow is represented as different compartments that change over the reproductive cycle. Nutrient flows considered are those of energy and digestible amino acids. Nutrients are used with the highest priority for maintenance and uterine growth or milk production. Subsequently, deposition and/or mobilisation of body proteins and lipids are determined and used for estimating the changes in body weight and backfat thickness of the sow. A decision support tool was built from the set of equations given, with additional modules to describe animal's characteristics and adjust some model parameters to account for variations in genotypes and performance. This tool can be used to determine energy and amino acids requirements of sows according to production objectives, or to predict body composition changes according to a given feeding strategy and to evaluate the effects of different nutritional strategies on nutrient utilisation, performance, faeces production and composition, and volatile emissions from the faeces. The simulation of the pig growth and carcass characteristics are based on the Inraporc model, as described by (Dourmad et al.., 2008). This model is integrated with the MESPRO model, which estimates the amount and composition of faeces from fattening pigs (Aarnink et al.., 1992), thereby assuming that the principles for fattening pigs are comparable with reproductive sows. The total nitrogen excretion (TAN) was calculated according to Velthof et al.. (2009).

6.4.1 Performance reproductive sows

The process of reproduction, from conception to weaning, can be considered as directed to buffer the developing progeny from nutritional distress and involves both homeostatic and homeorhetic controls of nutrient partitioning. During pregnancy, sufficient body reserves must be built to compensate for the eventual nutritional deficit that may occur in the following lactation. However, these reserves should not be excessive in order to avoid the occurrence of farrowing problems that are typical for fat sows, or to impair feed intake after farrowing. During lactation, it is recommended to adapt nutritional supplies to requirements in order to maximise milk production and piglet's growth, and minimise reproductive problems of sows after weaning. Consequently, nutritional supplies to sows
must be adapted to maintain body reserves in optimal condition all along their productive life and optimise their reproductive performance. This decision support tool includes a simulation model that represents on a daily basis (dynamic) the utilisation of key nutrient pools (mechanistic) for a given sow (deterministic).
A simplified description of nutrient utilisation by the sow is given in Figure 14.

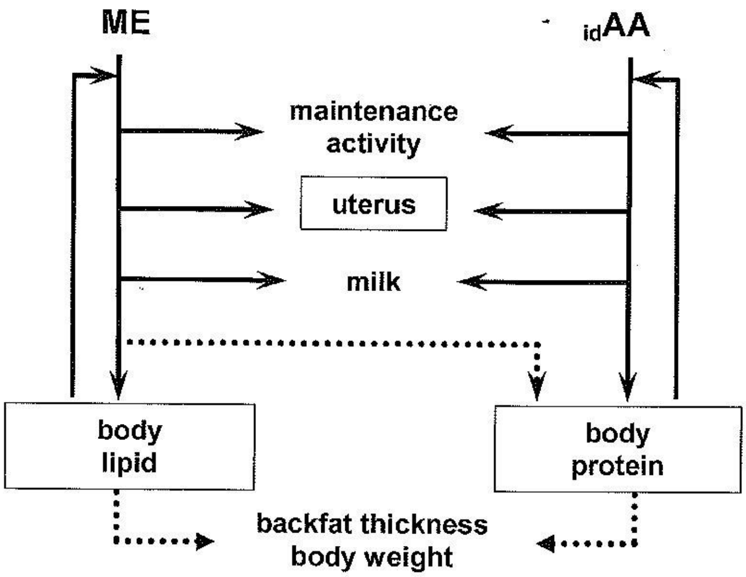


Figure 14. Description of nutrient utilisation in the sow model

The sow is represented as the sum of different compartments (i.e., body protein, body lipids and uterus), which change during the reproductive cycle. The main nutrient flows concern energy and amino acids. In pregnant sows, priority is given to maintenance requirements and requirements for foetuses, uterus and mammary gland development. If nutrient allowances exceed these requirements, nutrients in excess contribute to the constitution of sow's body reserves. Conversely, body reserves will be mobilised in the case of a nutrient deficiency. In lactating sows, priority is given to maintenance and milk production. Body reserves often contribute to the supply for these priority functions. Inraporc maintained the concept of ME in the sow model, which is differing from the used NE system in the Netherlands. ME value of feed is calculated by multiplying EW-value of diet by the factor 12.46. The supply of amino acids is considered as standardized ileal amino acid. A detailed description of all the calculations are provided in the paper of Dourmad et al.. (2008) and will not be included here.

6.4.2 Faeces production and composition reproductive sows

For calculation of the faeces production and composition, the same sets of equations is used as described for the growing-finishing pigs. Deviant from this, water deposition in maternal and foetal tissues is added to the calculation of water excretion.

6.5 Animal model broilers

The simulation of the growth of the broilers is based on the BPHL model as described by King (2001). This model is a mechanistic, deterministic and dynamic approach to the evaluation of the effects of diet on broiler carcass composition and growth. This model provides insight in the amount of nutrients and water consumed by the birds, accreted in the broiler body, and about the remaining nutrients that are excreted. Regarding the nutrient excretions, in general the same calculation system as in the growing-finishing model is applied.

6.5.1 Broiler performance

Daily growth is simulated with information on the initial age and live weight of the bird, number of days over which the diet is to be fed, protein and amino acid densities of the diet, dietary metabolizable energy, and whether feed intake is to be simulated or data provided. Output provides information on a daily basis with respect to daily and accumulated deposition and current bird status for protein, fat, water, and ash body content. Carcass weight, feather weight, live weight, feed eaten, feed deprivation heat loss, limiting amino acids, feed conversion ratio, and percentage carcass fat are also provided. The approach employs empirically derived first-limiting amino acid coefficients relating to accretion efficiency and dietary concentration to define limits of protein retention, uses mathematical

expressions describing feed intake and heat loss trajectories as datum patterns prescriptive of the strain, introduces calibration as a device for improving correspondence between simulated and field performance, and relies on an assumption that deviations to the datum patterns of food intake and heat output caused by strain and environmental factors can be duplicated by simple multipliers acting on the expressions.
The limiting essential amino acids (AA) are determined by predicting the daily requirements for maintenance, tissue protein, and feather AA and comparing these assessments with ingested AA. The program readjusts the dietary concentration of the program-declared first-limiting AA, isoleucine, so that isoleucine is equally first limiting with that or a product of those found limiting. Protein is accreted in the carcass and feathers in keeping with strain-, sex-, and age-dependent, empirically determined constants describing the efficiency of accretion of isoleucine when it is first limiting. The energy cost of the daily protein deposited is determined using a protein energetic efficiency constant. Upon subtraction from the daily ME ingested, a measure of the dietary ME available for other functions is obtained. Heat output during feed withdrawal is established using a body weight function that may be adjusted by an accessible calibration factor. Together they influence the estimate of the daily deposition of body fat, and the calibration factor provides a means of matching simulated body fat levels with those observed in the field. The ME remaining after subtracting heat loss during feed withdrawal from the daily ME residual is available for fat accretion. Its amount is obtained by dividing the residual by a fat energetic efficiency factor. Bird weight is determined on a daily basis by summing the daily contributions of feather growth, carcass growth, and change in the weight of intestinal contents and adding it to the live weight computed for the preceding cycle. The output provides information on a daily basis or, alternatively, for the end of a growth stage with respect to daily and accumulated deposition and current bird status for protein, fat, water, and ash body content. Carcass weight, feather weight, live weight, feed eaten, heat loss during feed withdrawal, limiting amino acids, feed conversion ratio, and percentage carcass fat are also provided. The extent of the limitation of each essential AA found to be limiting is specified as a proportion, i.e., relative to one in supplementary screens to those registering daily bird status.

6.5.2 Faeces production and composition broilers

For calculation of the faeces production and composition, the same sets of equations is used as described for the growing-finishing pigs. Deviant from this, N-excretion by the urine is multiplied by the factor 140/28 to calculate the uric acid excretion. The body surface of the birds is determining the amount of water evaporation. In this model, water evaporation is set to be 10% * body surface. By using this factor, water excretion is in line with the values provides by Van Middelkoop (1993). The user, however, can provide the real DM content of the litter.

6.6 Animal model laying hens

The scientific basis of this model is described by the following authors (Johnston and Gous, 2007 ; Van Middelkoop, 1993 ; Van Krimpen et al.., To be submitted ; Van Krimpen et al.., 2011).

6.6.1 Laying hen performance

The input of the model starts with a description of the expected hen performance during the laying period in terms of rate of lay and egg weight. Based on several parameters, as defined by the user, the development of rate of lay and potential egg weight over time is provided, where after potential egg mass is calculated on a daily basis. Subsequently, energy requirement is calculated, thereby taken body weight, body weight gain, ambient temperature, feather cover, and housing system into account (Van Krimpen et al.., To be submitted). Then, feed intake is calculated by dividing energy intake by the energy content of the diet. Based on this feed intake level, digestible amino acid intake levels are calculated. Because methionine is the first limiting amino acid, the realized produced amount of egg mass is calculated by a model, in which methionine intake is included (Van Krimpen et al.., 2011). Intake of other essential amino acids, relative to methionine, is calculated. Realized egg mass is determined by the methionine intake or, in case of deficiency, by the intake of one the other amino acids. The subdivision of the egg into yolk, albumin and egg shell is based on functions provided by Johnston and Gous (2007), whereas subdivision of body gain in body fat and body protein is based on Van Krimpen et al.. (To be submitted).

6.6.2 Faeces production and composition laying hens

For calculation of the faeces production and composition, the same sets of equations is used as described for the growing-finishing pigs. Deviant from this, N-excretion by the urine is multiplied by the factor 140/28 to calculate the uric acid excretion. The body surface of the birds is determining the amount of water evaporation. In this model, water evaporation is set to be 6% * body surface, thereby using the equation for broilers for calculation of body surface (King, 2001). By using this factor, water excretion is in line with the values provides by Van Middelkoop (1993). The user, however, can provide the real DM content of the litter.

7 Transport

7.1 Transport matters

An inventory performed by Blonk et al.. (2008), reported that the contribution of greenhouse gas emission of transportation to the total GHG emissions of meat products varied strongly. For beef from a suckler system in Ireland, transport contributes less than four percent to total greenhouse gas emission, whereas for pork this contribution is 16 percent. It can thus be concluded that the relevance of computing greenhouse gas emissions related to transport in a detailed manner differs between animal products. For means of consistency we propose not to discriminate between computations related to transport of different products, but to use one standardised methodology for all feed ingredients. It has to be noted that ‘transport’ in this paper refers explicitly to transport of animal feed and feed ingredients and not to transport of animals.

7.2 Reference units

The reference unit for describing transport is directly related to the units that are used as output of crop production, processing, and feed mill, 1000 kg of product.
Transport is considered to occur after every step in the feed production chain. This can be transport of crop products from arable farm directly to the livestock farm, but also going to industrial processing. The co products from processing are transported to the feed mill etc. Every transport is defined by a) the distance between the point of departure (D) and the point of arrival (A); b) the used transport modalities. This can be one or more. The final unit used to calculate transport is the transport of 1000 kg of product over 1 kilometre with transport modalities T_1 - T_x (tonkm) and c) the transport efficiency, which includes loading of the transport modality, quality of roads, etc.
The GHG emissions from transport were calculated by applying background data on the use of a transport modality, expressed as g CO_2-equivalents per tonkm. Background data will be described in chapter 8.

7.3 System boundary

Ecoinvent discriminates between “operational” emissions (emissions during the transportation itself) and emissions from constructing infrastructure, buildings and the transport modalities (trains, boats etc.) themselves. The latter emissions are called “production” emissions in this document.
Ecoinvent therefore provides two emission factors:

1) “Operational” emission factor (kg CO_2/km)
2) “Operational + production” emission factor (kg CO_2/tonkm)

The difference between “Operational” and “Production” emissions can differ by 15% (Hischier et al.., 2009; Van Kernebeek and Splinter, 2011).
Ecoinvent provides the emission factors of a number of types of trucks, trains, ships and airplanes. These are based on European and/or Swiss transport characteristics. The emission factors provided by Ecoinvent are computed based on calculation rules. With this, Ecoinvent offers good flexibility to calculate emissions for specific transport situations.

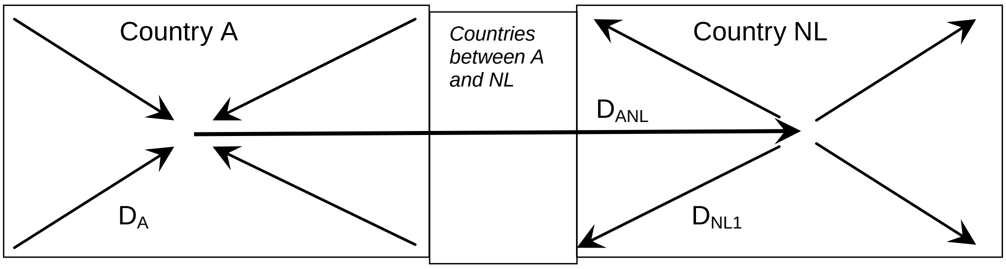
7.4 Transport distances and modalities

<u>Place of departure and of arrival</u>
In case studies, the places of departure and arrival of agricultural commodities can be known in detail. For the development of a database with default values, no exact locations can be defined. For all transport modalities, the place of departure and arrival will be chosen by making standardised approach following the chain description of the particular product. This procedure follows the same principles as used by Agrifirm to produce the yearly overview of computed distances products travel (Buijsse, 2011a).

The procedure for defining transport places is based on a set of basic principles:

- Feed materials used in the Netherlands, but grown in other countries can be processed in the country where the crop or basic animal product is produced, but can also be processed in the Netherlands.
- When a product is transported to the next step in the chain within the same country, the distance is based on the geographic midpoint of a country or of the most important crop production area to the location where the product is processed. When the product is transported by sea ship after processing, the location of processing is considered to be the largest port in a country. In case of transport by inland vessels after processing, the largest inland port is chosen as the location for processing.
- Transport of end products within the Netherlands is based on a standardised inland transport distance.

7.4.1 Transport from country A to NL by truck



Crop and processing in the same country, feed mill and farm in NL.

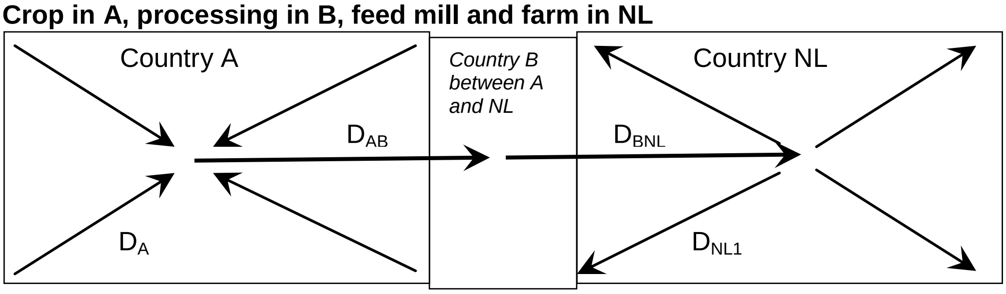
- the crop is transported from the field to the processing plant. The distance between processing plant and crop location is not known, neither is the number of processing plants. We use the inland distance for transport from field to processing plant.
- When the co product is transported from country A to B, we go from the one midpoint to the other. This is assumed to be the average distance between locations in both countries. No extra inland transport in country A or NL is incorporated.
- Inland transport in country NL is treated similar as the inland transport in country A, using the average distance for inland transport in NL.

D_A, D_{ANL} and D_{NL} are defined in the data tables. D_{NL1} is inland transport by truck, 93 km.

Crop in country A, processing , feed mill and farm in NL.

- When the crop is transported from country A to NL, we go from the one midpoint to the other. This is assumed to be the average distance between locations in both countries. No extra inland transport in country A or NL is incorporated.
- Inland transport in country NL from processing to feed mill and from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.

Crop in A, processing in B, feed mill and farm in NL



- When the crop is transported from country A to B by truck, we go from the one midpoint to the other. This is assumed to be the average distance between locations in both countries. No extra inland transport in country A or B is incorporated.

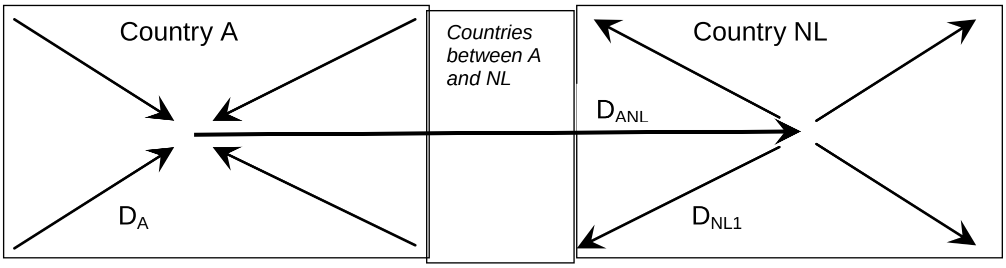
- Transport from country B (processing) to NL (feed mill) goes from midpoint to midpoint.
- Inland transport in country NL from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.

The approach for between country transport by truck is summarized in **Table 34**.

Table 34. Transport distances from country A to NL in case of truck transport.

Production phase	Country/ *distance*	Country/ *distance*	Country/ *distance*
Crop	A	A	A
transport	D_A	D_{ANL}	D_{AB}
Processing	A	NL	B
transport	D_{ANL}	D_{NL1}	B_{BNL}
Feed mill	NL	NL	NL
transport	D_{NL1}	D_{NL1}	D_{NL1}
Farm	NL	NL	NL

7.4.2 Transport from country A to NL by inland ship



Crop and processing in the same country, feed mill and farm in NL.

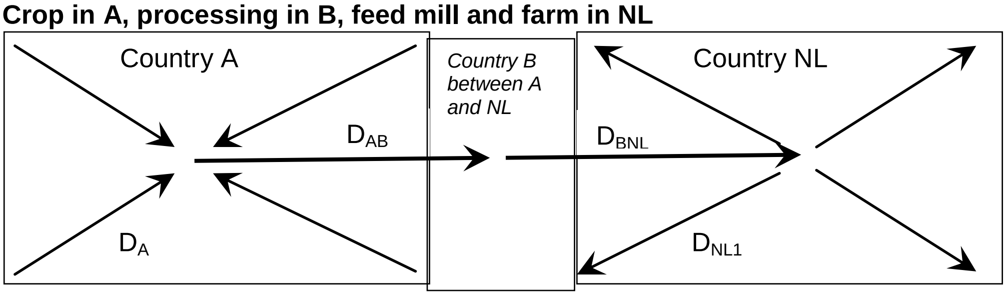
- the crop is transported from the field to the processing plant. The distance between processing plant and crop location is not known, neither is the number of processing plants. We use the inland distance for transport from field to processing plant.
- After processing, the co-product is transported from country A to NL, from the one midpoint to the other. This is assumed to be the average distance between locations in both countries. No extra inland transport in NL is incorporated.
- Inland transport in country NL is treated similar as the inland transport in country A, using the average distance for inland transport in NL.

D_A, D_{ANL} and D_{NL} are defined in the data tables. D_{NL1} is inland transport by truck, 93 km.

Crop in country A, processing , feed mill and farm in NL.

- When the crop is transported from country A to NL, the crop is transported to the inland port, assuming distance of D_A. From there it is transported by ship. No extra inland transport in country A or NL is incorporated.
- Inland transport in country NL from processing to feed mill and from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.

Crop in A, processing in B, feed mill and farm in NL



Transport from A to B by truck, B to NL by inland ship

- The crop is transported from country A to B (processing) midpoint to midpoint by truck, distance =D_{AB}.
- After processing the product is shipped from country B midpoint to NL (midpoint) by inland ship, distance = D_{BNL}.
- Inland transport in country NL from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.

Transport from A to B and from B to NL by inland ship

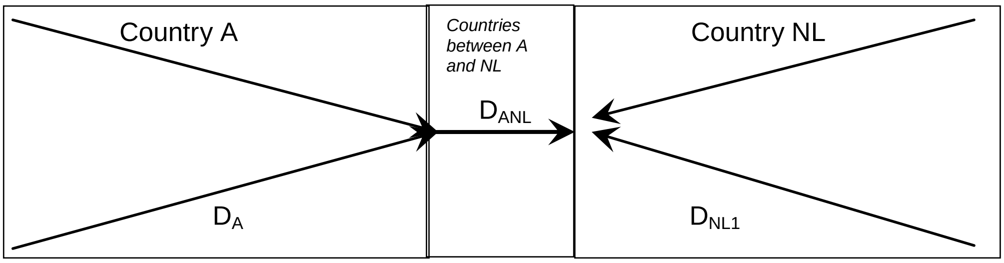
- The crop is transported to an inland port in country A and then shipped to country B. For transport to the inland port the average inland distance is used (D_A). Transport from A to B is the standard distance =D_{AB}. Processing takes place at the inland port. So there is no extra transport in country B.
- As a consequence transport from country B to NL by inland ship is from midpoint to midpoint, distance = D_{BNL}.
- Inland transport in country NL from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.

The approach for between country transport by inland ship is summarized in Table 35.

Table 35. Transport distances from country A to NL in case of transport to NL by inland ship.

Production phase	Country/ *distance*	Country/ *distance*	Country/ *distance*	Country/ *distance*
Crop	A	A	A	A
transport	D_A	$D_A + D_{ANL}$	D_{AB}	$D_A + D_{AB}$
Processing	A	NL	B	B
transport	D_{ANL}	D_{NL1}	D_{BNL}	D_{BNL}
Feed mill	NL	NL	NL	NL
transport	D_{NL1}	D_{NL1}	D_{NL1}	D_{NL1}
Farm	NL	NL	NL	NL

7.4.3 Transport from country A to NL by sea ship



Crop and processing in the same country, feed mill and farm in NL.

- the crop is transported from the field to the processing plant. The distance between processing plant and crop location is not known, neither is the number of processing plants. The plant is assumed to be located at the seaport.
- After processing, the co-product is transported from country A to NL, from the one seaport to the other. Inland transport in NL is incorporated. It consists of transport by inland ship and truck, 80 and 20 % respectively. This is written as D_{NL2}
- Inland transport in country NL is treated similar as the inland transport in country A, using the average distance for inland transport in NL.

D_A, D_{ANL} and D_{NL} are defined in the data tables. D_{NL1} is inland transport by truck, 93 km.

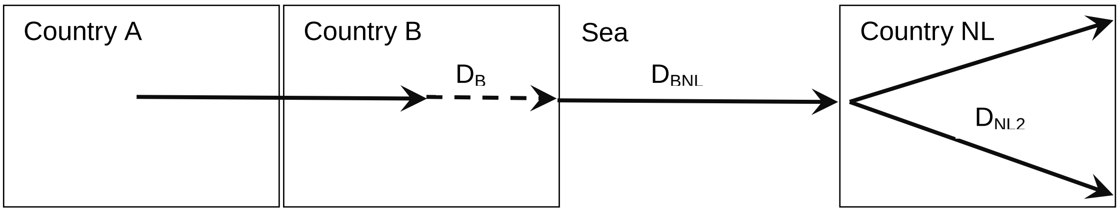
Crop in country A, processing , feed mill and farm in NL.

- When the crop is transported from country A to NL, the crop is transported to the seaport, assuming distance of $D_{A.}$ From there it is transported by sea ship. No inland transport in country NL is incorporated. It is assumed that the crop is processed close to the seaport.
- Inland transport in country NL from processing to feed mill is based on inland ship and truck, for 80 and 20 % respectively. For that D_{NL2} is used. Transport from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.

Crop in A, processing in B, feed mill and farm in NL

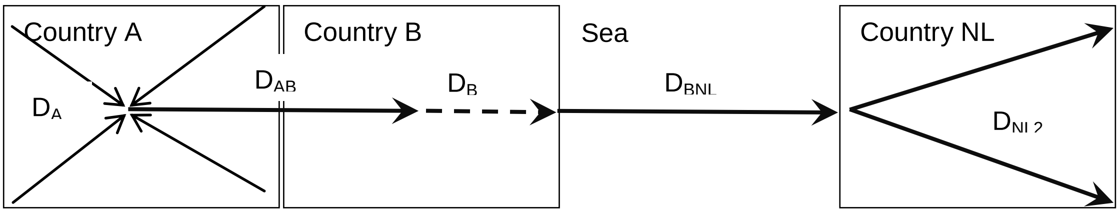
Transport A to B by truck, B to NL by sea ship

- Transport from country A to country B by truck goes from midpoint to midpoint, distance = D_{AB}.
- Transport from country B to NL goes from midpoint to port by truck (or inland ship), which is D_B, followed by transport from B to NL by sea ship, which is D_{BNL}. In NL it is immediately transported to the feed mill, which is D_{NL2}.
- Transport from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.



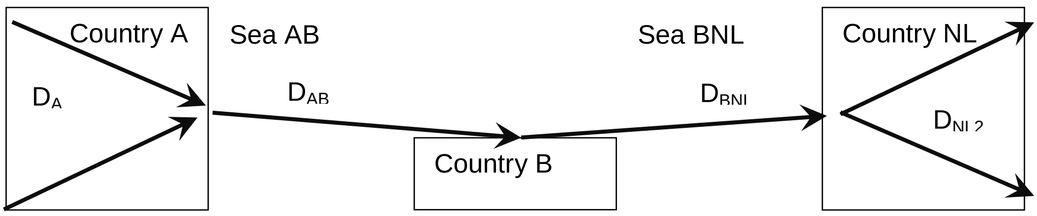
Transport A to B by inland ship, B to NL by sea ship

- Transport from country A to country B by truck goes from inland port to inland port, which is assumed to be the same as the midpoint distance, D_A. From the inland port the midpoint to midpoint distance between countries A and B is used = D_{AB}.
- Transport from country B to NL goes from midpoint to port by truck (or inland ship), to the seaport, which is D_B, followed by transport from B to NL by sea ship, which is D_{BNL}. In NL it is immediately transported to the feed mill, which is D_{NL2}.
- Transport from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.



Transport A to B by sea ship, B to NL by sea ship

- When the crop is transported from country A to B, the crop is transported to the seaport, assuming distance of $D_{A.}$ From there it is transported by sea ship. No inland transport in country B is incorporated. It is assumed that the crop is processed close to the seaport.
- Transport from country B to NL is port to port. From the seaport is goes to the feed mill via inland ship and truck, 80 and 20 % respectively. For that D_{NL2} is used.
- Transport from feed mill to farm is calculated by using the average distance for inland transport in NL: D_{NL1}.



The approach for between country transport by sea ship is summarized in **Table 36**.

Table 36. Transport distances from country A to NL in case of transport to NL by sea ship.

Production phase	Country/ *distance*	Country/ *distance*	Country/ *distance*	Country/ *distance*	Country/ *distance*
Crop	A	A	A	A	A
transport	D_A	$D_A + D_{ANL}$	D_{AB}	$D_A + D_{AB}$	$D_A + D_{AB}$
Processing	A	NL	B	B	B
transport	$D_{ANL} + D_{NL2}$	D_{NL2}	$D_{BNL} + D_{NL2}$	$D_{BNL} + D_{NL2}$	$D_{BNL} + D_{NL2}$
Feed mill	NL	NL	NL	NL	NL
transport	D_{NL1}	D_{NL1}	D_{NL1}	D_{NL1}	D_{NL1}
Farm	NL	NL	NL	NL	NL

The basic method was to define the geographic midpoint of a country. This can be found by using the Geographic Midpoint Calculator (http://www.geomidpoint.com/). More detailed information of cropping areas was preferred over the geographic midpoint approach. Information of main cropping areas was based on literature search and country statics.
The definition of the geographic midpoint and the largest seaport of Australia have been modified, due to the fact that agricultural production takes place at the coast and that the selection of the port has a large effect on the transport distance.

Calculating distances

Several countries have a distance calculator available for computing **train** distances for transport within their national train network. When these are available for a country, they will be used. Otherwise, the same methodology will be used as described for truck distances. For the UK, the travel footprint website can be used to compute the travel distance by train. The website is http://www.travelfootprint.org/. For India, the website http://www.realindiatours.com/distance-calculator.html will be used. Should there be any other country for which the train is used as a transport modality, than it should be checked whether for this particular country a distance calculator is available.
Truck distances are computed using Google maps. When multiple options are provided from starting point to destination, the shortest route will be taken.
Oversea transport distances from harbour to harbour are collected on Portworld (http://www.portworld.com/map/). On the online distance calculator of Portworld, the specific starting port and destination port are filled out and the distance (in kilometres) is calculated. When for a given country Portworld does not provide a port, a port was chosen (preferably the capital of the country) and the transport distance was computed using the online distance calculator of Sea Rates (SeaRates, 2011). The distance in nautic miles was converted to kilometres using the conversion factor of 1.852.
PC Navigo is an online tool for computing transport distances for **inland vessels**. Since no free online tool exists to compute the distance via inland vessel transport, the transport distance will be computed on Google maps by filling in the exact starting point and the destination point, including as many in-between ports as necessary to imitate the inland vessel waterways. The map of European inland vessel waterways can be found at Bureau Voorlichting Binnenvaart (2011).
Distances travelled by **shortsea ship** will prior be computed by using the online tool of portworld (http://www.portworld.com/map/). When either the starting port or the destination port or both are not present in portworld, the port(s) closest to the starting or destination port will be selected and a correction will be made using google maps.

Transport modalities

Transport within the Netherlands is mainly by truck (Van der Weide, 2011).
Inlands vessels floating in Germany mainly carry a volume of 1000-4000 ton (Van der Weide, 2011). Vessels in France are smaller and carry mainly 600 ton (Bolle, 2011).
The carrying capacity of sea ships generally used for shipping bulk cargo (wheat and soybean) overseas ranges between 3.000 and 300.000 ton (Bulk carrier guide, 2010). Barling (2011) suggests that wheat and soy from South America is usually traded by Panamax vessel, of which the carrying capacity can vary widely. Dry bulk tankers can be segregated between Handy size vessels with a carrying capacity between 20.000 to 35.000 ton (which are accessible to many ports), Panamax vessels with a carrying capacity of 50.000 – 80.000 ton and Cape size vessels with a carrying capacity of 100.000 to 300.000 ton (which can only access the largest seaports and cannot pass through the Panama Canal) (Bradley et al.,. 2009).

<u>The transport matrix</u>

A transport matrix has been constructed where transport within countries and between countries is defined. All relevant modalities have been defined. When products are transported from Australia to the Netherlands, sea transport plays an important role. The transport in Australia is to bring products to Fremantle or Sydney, when the imported product is processed in the Netherlands, this is assumed to occur close to the sea port and no transport is calculated. When the imported product is already processed, the transport in the Netherlands goes to the feed mills. The transport data reflect the average situation.

The advantage of the matrix is that it can be used in two ways, from country A to B, but also the other way around.

Table 37. A selection of the transport matrix for the use in the calculation tool. The figures ….1 and …2 indicate the country of departure and the country of arrival.

from Land1	Australia	Belgium	Brazil	Canada	the Netherlands
to Land2	the Netherlands	the Netherlands	the Netherlands	the Netherlands	the Netherlands
Lorry1	400	212	1077	2000	93
Train1	100				
SeaShip	19668		9,684	5,124	-
Inlandship1			0		
Airplane					
Lorry2	19		19	19	
Train2					
Inlandship2	108		108	108	

8 Background data

8.1 N, P, K fertilizers

Approach

The use and production of fertilizers differ between regions in the world. Therefore, six global regions are defined to calculate regional specific GHG emissions for fertilizer production and fertilizer use in:

1. Western Europe
2. Eastern Europe (including Russia)
3. South America
4. North America
5. Asia
6. Australia

In each region a specific mix of N, P and K fertilizers is determined, using data from the International Fertilizer Association. From data about total N, P and K fertilizer application rates in each crop and country, the share of different N, P and K fertilizers will be calculated.

In each region the production of fertilizers leads to different GHG emissions. In the second part of this paragraph the GHG emissions of a number of N, P and K fertilizers is explained. These regional specific GHG emissions will be used to calculate the contribution of fertilizer production to the GHG emissions of fertilizer applications.

Fertilizer use

The share of different N, P and K-fertilizers is derived from data from the IFA and are summarized in Table 38, Table 39 and Table 40.

Table 38. The share of different N-fertilizers in total N-fertilizer use in the different global regions. Figures are calculated averages for 2004 - 2008

	Urea	Nitrogen solutions	NPK compound	Anhydrous Ammonia (direct)	AN	CAN	AP	AS
World average	31%	14%	12%	12%	9%	8%	5%	5%
Western Europe	18%	11%	19%	0.1%	18%	24%	2%	3%
Eastern Europe (incl. Russia)	19%	5%	11%	0%	56%	1%	5%	4%
South America	52%	4%	7%	0%	9%	1%	14%	12%
North America	23%	24%	10%	28%	3%	0.1%	6%	3%
Asia	78%	0%	8%	0%	0.1%	0%	1%	11%
Australia	55%	7%	6%	6%	0.1%	1%	19%	7%

CAN = Calcium Ammonium Nitrate, AN = Ammonium Nitrate, AP = Ammonium Phosphate, AS = Ammonium Sulphate

Table 39. The share of different P-fertilizers in total P-fertilizer use in the different global regions. Figures are calculated averages for 2004 - 2008

	AP	NPK compound	TSP	SSP	Other NP	PK compound	Ground rock
World average	45%	26%	11%	9%	3%	2%	2%
Western Europe	22%	52%	8%	1%	4%	10%	0%
Eastern Europe (incl. Russia)	56%	31%	0%	0%	7%	0%	6%
South America	46%	3%	21%	26%	0%	0%	3%
North America	63%	27%	0	0%	6%	0%	0%
Asia	10%	30%	39%	1%	6%	0%	14%
Australia	64%	31%	5%	0%	0%	0%	0%

TSP = Triple superphosphate, SSP = Single superphosphate

Table 40. The share of different K-fertilizers in total K-fertilizer use in the different global regions. Figures are calculated averages for 2004 - 2008

	Potassium chloride	NPK compound	Potassium sulphate	PK compound	NK compound
World average	68%	26%	2%	2%	1%
Western Europe	29%	55%	4%	10%	0%
Eastern Europe (incl Russia)	56%	43%	1%	0%	0%
South America	97%	1%	1%	0%	1%
Argentina	47%	13%	15%	0%	25%
North America	67%	26%	4%	0%	1%
Asia	77%	22%	1%	0%	0%
Australia	18%	68%	11%	0%	2%

Fertilizer production

The greenhouse gas emissions and primary energy use for synthetic fertilizer production is calculated from cradle to gate of the fertilizer plant.

8.1.1 Ammonia and nitric acid production

Ammonia and nitric acid are raw materials for many fertilizers. Natural gas is the main raw material for ammonia production and also the main fuel for ammonia, nitric acid and fertilizer production. Therefore the impact (on greenhouse gas emissions and fossil energy depletion) of the complete life cycle of natural gas is taken into account.

Ammonia

Natural gas is the main raw material for ammonia production with approximately 80% of world ammonia capacity being based on natural gas (EFMA 2000a and Patyk 1996). IEA (2007) confirms with more recent figures that on global level in 2005 natural gas is the main feed for ammonia production, but in some regions other fuels are used in much larger extend. In China and India 80% and 50% respectively of the ammonia production is based on other fossil fuels as oil and coal. China and India represent a significant part in global ammonia production, 30% and 8% respectively. The global ammonia production excluding production in China and India is 98% based on natural gas (IEA 2007)

The production of ammonia is a very energy demanding process. In Table 41, the share of different fossil fuels used as raw material for ammonia production and energy efficiency are summarized.

Table 41. The share of different fossil fuels used as feed and fuel for ammonia production and the energy efficiency of ammonia production in different global regions (IEA 2007)

	gas	oil	coal	GJ/t NH_3
Western Europe	100%			35.0
North America	100%			37.9
Russia + Central Europe	98.9%	1.1%		40.7
China + India	26.5%	18.7%	54.7%	47.6
Rest of the world	100%			36.4
World average	70.7 %	8.2%	21.0%	41.5

The greenhouse gas emissions and energy use from cradle (production or mining fossil fuel) to gate of ammonia plant can be calculated combining the energy use figures and additional greenhouse gas emissions and energy use per MJ fuel used.

Nitric Acid

All nitric acid production is based on the same basic chemical reactions: oxidation of ammonia with air to give nitric oxide, oxidation of the nitric oxide to nitrogen dioxide and absorption in water to give a solution of nitric acid.

The amount of N2O emitted depends on combustion conditions (pressure, temperatures), catalyst composition, burner design (EFMA 2000b) and emissions abatement technologies (IPCC 2000). Non-Selective Catalytic Reduction (NSCR), a typical tail gas treatment in the USA and Canada, may

reduce N2O emissions by 80-90% (IPCC 2000) and a nitric acid manufacturer in Norway has developed a N2O abatement process giving 70-85% N2O reduction (Kongshaug 1998). Despite their advantages, an estimated 80% of the nitric acid plants worldwide do not employ NSCR technology (IPCC 2000).
Table 42 contains figures of N2O emissions related to nitric acid production in the different global regions.

Table 42. The average, minimum and maximum dinitrous oxide emissions at nitric acid production

Global region	average	minimum	maximum
Western Europe	7	0.01	12
North America	7	1.85	12
Russia + Central Europe	7	4	19
China + India	7	4	19
Rest of the world	7	4	19
World average	7	0.01	19

The greenhouse gas emissions per ton nitric acid varies between 2.8 t CO2 eq./t nitric acid at plants in Europe, North America and rest of the world to 3.6 t CO2 eq./t nitric acid at plants in China and India.

8.1.2 Phosphate P-building blocks and other fertilizer components

The phosphate in P-fertilizers originates from mined phosphate rock and/or synthetically produced phosphoric acid. The energy required for mining phosphate rock depends on the accessibility of the ore and varies between 0.3 and 2.8 GJ/ton. Modern phosphoric acid plants produce a surplus of energy, less modern plants don’t. The production of sulphuric acid (used as S-source in fertilizers) also leads to a surplus energy production.
The potassium fertilizers Potassium Chloride and Potassium Sulphate are mined, whereas Potassium Sulphate can also be synthesized. In this synthetic production the most efficient techniques produce a surplus of energy.

Composition of fertilizers
The amount of raw materials to per fertilizer and the energy use for production is summarized in Table 43, Table 44 and Table 45. These data are based on Kongshaug (1998).

Table 43. Amounts of substances and energy needed to produce 1 ton N-fertilizer

Substance	unit	Urea	Nitrogen solutions (liquid UAN)	Anhydrous Ammonia	Ammonium Nitrate	Calcium Ammonium Nitrate	Ammonium Sulphate
Ammonia	kg	567		1000	219		255
Nitric Acid	kg				812		
Urea	kg		348				
Ammonium Nitrate	kg		457			756	
Dolomite	kg					244	
Sulphuric acid	kg						590
Energy	GJ	4.14	0.13		0.7 (0.15-1.4)		

Table 44. Amounts of substances and energy needed to produce 1 ton P and/or K-fertilizer

Substance	unit	Triple Super Phosphate	Single Super Phosphate	Ground rock	Potassium chloride	Potassium sulphate
Phosphate rock	Kg	144		1000		
Phosphoric acid	Kg	336	210			
Sulphuric acid	Kg		367.5			
Muriate of Potash	Kg				1000	
Sulphate of Potash	Kg					1000
Energy	GJ	2	1.4			

Table 45. Amounts of substances and energy needed to produce 1 ton Compound-fertilizer

Substance	unit	Mono-Ammonium Phosphate (MAP)	Di-Ammonium Phosphate (DAP)	NPK compound	NPK compound	NK compound	PK
Ammonia	Kg	134	219				
Nitric Acid	Kg					630	
phosphoric acid	Kg	520	460				
Muriate of Potash	Kg			250	250	730	370
Mono-Ammonium Phosphate (MAP)	Kg			144			
Di-Ammonium Phosphate (DAP)	Kg			163			
Urea					330		
Ammonium Nitrate	Kg			330			
Triple Super Phosphate					310		460
inert	Kg			110	110		180
energy	GJ	0.9				6	

<u>GHG emissions fertilizers</u>

With the above information the GHG emissions for different types of fertilizer per global region can be calculated. The results of these calculations are summarized in Table 46,Table 47 and Table **48**.

There are big differences between different types of fertilizer and between different regions. In Europe the GHG emissions per kg N varies from 2.14 for ammonium sulphate to 8.03 for CAN. And the GHG emissions for urea varies from 3.49 in Europe to 7.41 in China and India.

Table 46. The calculated GHG emissions (cradle to gate) for the most used N-fertilizers produced in different global regions (kg CO_2eq/per kg N) (Minimum and maximum values between brackets)

Global region	Urea	Nitrogen solutions (liquid UAN)	Anhydrous Ammonia	Ammonium Nitrate	Calcium Ammonium Nitrate	Ammonium Sulphate
World average	5.00 (4.41 - 5.63)	7.27 (2.65 – 16.75)	4.21 (3.27 – 5.29)	9.47 (6.60– 14.14)	9.51 (6.65 – 14.18)	3.33 (0.94 – 6.23)
Western Europe	3.49 (3.06 – 3.88)	5.77 (2.11 – 10.38)	2.85 (2.19 – 3.44)	7.99 (5.25 – 10.04)	8.03 (5.29 – 10.08)	2.14 (0.75 – 4.67)
Russia + central Europe	4.82 (4.41 - 5.36)	7.08 (4.51 – 14.11)	4.04 (3.44 – 4.98)	9.28 (7.94 – 13.89)	9.33 (7.98 – 13.93)	3.18 (1.37 – 5.84)
North America	3.75 (3.29 – 4.17)	6.04 (2.74 – 12.79)	3.11 (2.40 – 3.75)	8.27 (6.15 – 12.76)	8.31 (6.18 – 12.79)	2.40 (0.75 – 4.67)
China + India	7.41 (6.64 – 8.34)	9.65 (5.23 – 17.12)	6.36 (5.16 – 7.98)	11.80 (10.18 – 16.71)	11.86 (10.24–16.77)	5.20 (1.69 – 8.17)
Rest of world	3.63 (3.18 – 4.18)	5.91 (3.49 – 13.62)	2.99 (2.30 – 3.89)	8.14 (6.77 – 12.73)	8.18 (6.80 – 12.76)	2.28 (0.75 – 5.46)

Table 47. The calculated GHG emissions (cradle to gate) for the most used P- and K-fertilizers produced in different global regions compared to figures from literature (in kg CO2eq/per kg P2O5 or K2O) (Minimum and maximum values between brackets)

Global region	Triple Super Phosphate Per kg P_2O_5	Single Super Phosphate Per kg P_2O_5	Ground rock Per kg P_2O_5	Potassium chloride Per kg K_2O	Potassium sulphate Per kg K_2O
World average	0.45 (-0.05 - 0.63)	0.16 (-0.83 – 0.56)	0.23 (0.02 – 0.26)	0.69 (0.48 – 0.85)	0.23 (0.06 – 0.28)
Western Europe	0.36 (-0.04 – 0.52)	0.13 (-0.67 – 0.47)	0.19 (0.02 – 0.23)	0.56 (0.39 – 0.71)	0.19 (0.05 – 0.23)
Russia + central Europe	0.44 (-0.04 – 0.61)	0.16 (-0.80 – 0.53)	0.23 (0.02 – 0.24)	0.68 (0.49 – 0.82)	0.23 (0.16 -0.28)
North America	0.36 (-0.04 – 0.52)	0.13 (-0.67 – 0.47)	0.19 (0.02 – 0.23)	0.56 (0.39 – 0.71)	0.19 (0.05 – 0.23)
China + India	0.59 (-0.07 – 0.83)	0.21 (-1.10 – 0.74)	0.31 (0.03 – 0.34)	0.91 (0.62 – 1.12)	0.31 (0.08 – 0.37)
Rest of world	0.36 (-0.04 – 0.52)	0.13 (-0.67 – 0.47)	0.19 (0.02 – 0.23)	0.56 (0.39 – 0.71)	0.19 (0.05 – 0.23)

Table 48. The calculated GHG emissions (cradle to gate) for the most used compound fertilizers produced in different global regions (kg CO_2eq/per kg N or P_2O_5) (Minimum and maximum values between brackets)

Global region	Mono-Ammonium Phosphate (MAP)	Di-Ammonium Phosphate (DAP)	NPK compound (based on AN, AP and MOP)	NPK compound (based on Urea, TSP & MOP)	NK compound (based on nitric acid and MOP)	PK
	Per kg N	Per kg N	Per kg N	Per kg N	Per kg N	Per kg P_2O_5
World average	4.75 (1.21 – 6.42)	4.52 (2.39 – 5.67)	9.12 (7.57 – 11.14)	6.19 (5.54 – 6.68)	19.6 (14.1 – 28.4)	1.19 (0.84 – 1.37)
Western Europe	3.29 (0.47 – 4.52)	3.10 1.43 – 3.90)	7.47 (6.06 – 8.44)	4.45 (3.94 – 4.80)	17.1 (11.7 – 21.1)	0.97 (0.67 – 1.13)
Russia + central Europe	4.57 (1.27 – 6.14)	4.34 (2.42 – 5.41)	8.92 (7.97 - 10.89)	5.98 (5.44 – 6.41)	19.3 (16.7 – 27.9)	1.17 (0.83 – 1.33)
North America	3.55 (0.71 – 4.80)	3.36 (1.66 – 4.19)	7.75 (6.57 - 9.64)	4.71 (4.19 – 5.08)	17.3 (13.2 – 26.1)	0.97 (0.67 – 1.13)
China + India	7.06 (2.42 – 9.37)	6.76 (3.97 – 8.38)	11.75 (10.50 – 13.96)	8.98 (8.11 – 9.67)	23.7 (20.5 – 32.8)	1.57 (1.09 – 1.80)
Rest of world	3.42 (0.60 – 4.81)	3.24 (1.55 – 4.20)	7.62 (6.72 – 9.57)	4.59 (4.08 – 5.02)	17.2 (14.5 – 26.0)	0.97 (0.67 – 1.13)

8.2 Emissions from energy sources

Emissions from fossil fuel use

Fossil inputs and electricity are used in all types of unit processes of agri-food products. Greenhouse gas emissions arise primarily from the combustion of these fuels, where CO2 is directly emitted. In addition to these combustion emissions, GHG emissions (including methane and N2O emissions) occur due to the production and transportation of these fuels, the production of capital goods and the production and operation of the distributing grid. Values for the production and transportation are available per country (for example from Ecoinvent) but these are in general not available for all countries globally and the data quality may vary within a given dataset.

Contributions of upstream emissions can vary from 5% to almost 40% percent of emissions produced from combustion only [Blonk et al. 2010]. It was thus decided to use a single emission factor for fuels based on general averages. A good source for this is the BioGrace list of standard values (http://www.biograce.net/content/ghgcalculationtools/standardvalues), which were used for calculating the default values in the Renewable Energy Directive (2009/28/EC, Appendix 5). The relevant emission factors are listed in Table 49.

BioGrace lists the total end use emission factors including upstream emissions, but is not transparent on how these values are exactly deduced. The primary energy input required to produce a MJ worth of fuel is also listed by BioGrace, and also shown in the table. This gives an indication of contribution of the upstream emissions involved in the production of the fuel. For comparison, the IPCC combustion emission data are included for comparison to the total values provided by BioGrace. The ratio of the emission factor from BioGrace and the IPCC combustion emission values give insight into the amount of upstream emissions for each fuel (for example a little over 20% for natural gas).

Table 49. Emission factors based on BioGrace standard values*

Energy carrier	Emission factor (kg CO_2eq/MJ)	MJ_{fossil}/MJ ratio according to BioGrace	IPCC combustion emission (kg CO_2eq/MJ)	Ratio: BioGrace/IPCC
Natural gas	0.06759	1.13	0.056	1.21
Diesel	0.08764	1.16	0.074	1.18
Heavy fuel oil	0.08498	1.09	0.078	1.09
Hard coal	0.11128	1.09	0.096	1.16

* For reference, the LHV (MJ/kg) of diesel, HFO, and doal are defined as 43.1, 40.5 and 26.5 MJ/kg, respectively.

Emissions from electricity production

Electricity is generated by using fossil energy sources and other types of energy sources, such as nuclear power and hydropower. The mix of energy sources for electricity production is different for each electricity grid. National grids are often connected (Weber et al.., 2010) and customers can buy a specific electricity mix resulting in a complex situation to define the mix of sources. Furthermore, the efficiency of converting fossil energy to electricity varies depending on the type of technology used.

The energy mixes and combustion emissions for available countries were obtained from IEA data for the year 2008. The upstream GHG emissions of the related fuels present in the country's mix were taken into account using data from the Ecoinvent database. As stated earlier, these upstream emission factors are rather uncertain but in the case of electricity production have to be taken into account for the sake of completeness. The emissions thus calculated per kWh electricity in each country are shown in Table 50. The upstream emission factors for the specific fuel use in electricity production are obtained from Ecoinvent (combined with IPCC combustion emissions) per electricity source is given in Table 51.
IEA provides data about the amount of electricity that is produced from different sources like coal, oil, gas, nuclear, hydro and about the amount of heat that is produced from the same sources. CO2 emissions per kWh are calculated for each country following IPCC calculation rules. It should be noted that the IEA data include the emissions from the production of heat as well, which likely leads to a decrease.

Table 50. Emissions for electricity production (in g CO_2eq/kWh)*

Country	Combustion	Upstream	Total emissions
Argentina	365	76	440
Australia	849	109	958
Belgium	214	47	262
Brazil	89	19	108
Canada	182	33	215
Chile	411	65	476
China	719	97	816
Czech Republic	483	78	561
Denmark	330	86	415
France	60	18	78
Germany	424	74	498
Hungary	294	67	362
India	949	98	1047
Indonesia	751	100	850
Italy	404	89	494
Malaysia	656	104	760
Mexico	433	87	520
Niger	399	81	480
Nigeria	399	81	480
Norway	2	5	7
Pakistan	451	77	528
Peru	264	47	311
Philippines	487	76	562
Poland	656	114	769
Scotland	482	92	574
Spain	320	71	391
Thailand	531	103	634
Netherlands	377	98	475
Turkey	503	94	597
Ukraine	422	59	481
United Kingdom	482	92	574
United States	530	84	614
Vietnam	409	74	483
Uganda	242	46	288
Sudan	461	77	538

* Only countries relevant to the CFPAN project are listed.

Table 51. Upstream emission factors for electricity generation

Electricity source	g CO_2eq/kWh
Coal	119
Oil	112
Gas	109
Nuclear	8
Hydro	4
Wind	14
Other renewable energy source	13

Notes on uncertainty

As noted in chapter 3.8, the background data described here will not be subject to a quantitative uncertainty analysis within the Monte Carlo calculations. However, some qualitative remarks on this subject are appropriate here. The emissions stemming from the direct burning of fossil fuels are quite well known, and for a given fuel type do not vary much per MJ fuel and are generally considered to be reliable. However, for fuels a major source of uncertainty is the emissions related to the production and transportation of the fuel, the impact of which can vary significantly per country (ranging from 5% to almost 40% added to emissions from combustion only [Blonk et al. 2010]). For the electricity production numbers, additional uncertainties lie in the electricity mix and the efficiency of power plants in different countries. Although the IEA data does take these factors into account, some uncertainty will always remain. As a last point, already mentioned in the previous section, it should be mentioned that the figures per kWh electricity produced from the IEA include also heat production, and it is at this moment unclear what the contribution of this simplification is.

8.3 Emissions from additives

Life Cycle Assessment has been carried out for a limited number of synthetic amonio acids (Eriksson et al.., 2005; Marinussen & Kool, 2010). The detailed analysis of Marinussen & Kool shows high values of synthetic amnio acid production (see **Table 52**). The value, assumed by Eriksson et al.. (2005) of 3600 gram per kg of amino acid will not be used. For the amino acids without detailed analysis, the average value of the three amino acids of Marinussen and Bonk will be used.

Table 52. Emission factors for a limited set of feed additives

Name product	gram CO_2eq/kg product	Remarks
Methionine	5493	Average value of Denmark, Germany and France
Threonine	16978	Average value of Denmark, Germany and France
Lysine	6028	Average value of Denmark, Germany and France
Other synthetic amino acids (Valine, Arginine, Isoleucine, Tryptophane)	9300	Average of the three amino acids above
Chalk fine	19	Ecoinvent (2009)
Chalk grit	19	Ecoinvent (2009)
NaCl	18	Ecoinvent (2009)
$NaHCO_3$	1050	Ecoinvent (2009)
MgO	1060	Ecoinvent (2009)
Urea	1626	Kool and Marinussen (2012)

9 The GHG emissions of feed, results.

In the previous chapters, the methodology to calculate GHG emissions of feed materials has been described. A large part of the methodology is based on existing and widely accepted methods and calculation rules. Developing a complete overview of all feed materials requires adjustments in the methodology. It is impossible to be specific for all crops and production locations, as crops are produced in many countries and within countries in many regions, provinces or other sub national units. To develop a calculation tool that can be used at sector level, the concept of "Comparability goes over flexibility" of the Product Environmental Footprint Guide (JRC, 2012) has been applied and some parts of the methodology have been improved:

- The feed production chain has been broken down to a set of stages, with well-defined outputs. This breakdown allows feed materials to follow different routes to the animals' ration.
- The processing of agricultural products has been analysed in more detail, leading to more accurate calculations of GHG emissions for a number of wet co products.
- The calculation of emissions from Land Use Change has been simplified.
- The transport distances of and –modalities of products has been standardised.
- A well-defined methodology for data collection and assessing data quality has been applied, including the addition of a distribution type and range to all data. This allows to perform Monte Carlo simulations.

Three groups of feed materials are distinguished in FeedPrint:

- Roughages, fibrous materials, mainly used for ruminants
- (Wet) Co-products, originating from processed crops, directly supplied to farms and not being used in compound feed
- Feed raw materials, these can be crops or co products and are used as inputs for compound feed production. Co products have a high dry matter content by nature or are dried after cultivation or processing. In the feed production chain, compound feeds play an important role as feed for ruminants, pigs, chicken and veal.

The novel parts of the methodology will be explained and discussed on the basis of feed materials from these groups.

9.1 The breakdown of the feed production chain

Feed materials have a specific "route" through the feed production chain, Roughages, for example, are produced on-farm, are not transported over long distance and are used for animals (mostly ruminants) directly. However, roughages can be artificially dried and hence extending the production chain(**Table 53**). Many dried feed materials have a variety of routes through the feed production chain, such as feed grains. Feed grains are in some occasions directly fed to animals, after grinding at the farm, these can be ground at the feed mill and become part of a compound feed, or these are used in dry or wet milling and parts of the wheat are fed as a (wet) co product. The co products from wheat milling can also be used in compound feed production and are part of a compound feed.

Table 53. The different routes of feed ingredients through the feed production chain.

Product name	Crop production	Processing	Feed Mill	Transport	Animal	Example
Roughages	X	-	-	-	X	Grass
Roughages	X	X		X	X	Grass, articially dried
Feed materials 1	X	-	-	X	X	Wheat
Feed materials 2	X	-	X	X	X	Compound feed with wheat
Feed materials 3	X	X	-	X	X	Wheat middlings
Feed materials 4	X	X	X	X	X	Compound feed with middlings

9.1.1 Roughages.

Grass and lucerne can be used fresh, as silage or artificially dried, whereas maize can be used as silage and artificially dried (**Table 54**). In the case of artificially drying, a feed ingredient is transported from the farm to a drying facility and back. There is a wide range in dry matter contents of the roughages, ranging from 163 g/kg to 918 g/kg in grass. The other products have similar ranges. The total emissions of fresh grass are low compared to grass silage, but when a comparison is made on the basis of dry matter, GHG emissions of fresh grass are slightly higher. This is caused by the higher N-input to DM yield ratio in grass for grazing compared to grass for silage. The higher emissions related to the higher ratio are more than counteracting the lower emissions for machine use. Also in the case of similar effect is seen in lucerne, the differences on a dry matter basis are limited. Here the N-input to yield ratio is the same for both products and so is the mechanisation, but the conservation losses cause a slightly higher emission of the lucerne silage.

Table 54. The GHG emissions for cultivation, drying and transport for grass, maize and lucerne. All emissions are expressed as gram CO2-equivalents per kg of product, except the last line.

Product →	Grass, fresh	Grass silage	Grass dried	Maize silage	Maize dried	Lucerne, fresh	Lucerne, silage	Lucerne, dried
DM content (g/kg)	163	474	918	301	909	200	403	910
GHG emissions (g CO_2-equivalents / kg)								
Cultivation	87	240	201	49	49	68	149	68
Transport to process			35		35			35
Allocation factor			3.39		3.39			3.39
From cultivation (including allocation)			682		166			231
Processing (drying)	0	0	1168	0	1157	0	0	1168
Total of cultivation, processing and transport (sum of above)			1885		1358			1434
Transport to feed mill								
Feed mill								
End of feed mill								
Transport to farm	0	0	10	0	10	10	10	10
Animals' ration (product basis)	87	240	1895	49	1368	78	159	1444
Animals' ration (dry matter basis)	532	505	2064	163	1505	390	395	1587

Artificially drying is a very energy consuming process and leads to high GHG emissions per kg of product and per kg of dry matter. Emissions of dried products are 4 to 9 times higher than fresh or silage on a dry matter basis. The dry matter content of the roughages at arrival of the drying facility is on average 270 g/kg, despite differences in dry matter content at the moment of cutting. Because 3.39 kg of fresh product are needed for 1 kg of dried feed, the cultivation emissions of cultivation after allocation and transport of fresh grass, maize and lucerne are multiplied by 3.39.

9.1.2 The country of origin

FeedPrint provides the opportunity to source feed materials from different countries. The GHG emissions of the product are different per country, which is a consequence of differences in fertilizer rates, yields and transport distances. The most important factor determining the GHG emissions of the crop is the application rate of synthetic fertilizer nitrogen. It means that high application rates can lead to higher yields, but also to higher emission rates per kg of product (Table 55).

Table 55. GHG emissions of wheat cultivated in different countries and of transport from these countries to a feed mill in the Netherlands.

	Germany	France	Netherlands	United Kingdom
N input organic manure (kg/ha)	62	29	170	39
N input synthetic fertilizer (kg/ha)	150	119	145	192
Yield wheat grains (kg/ha)	7129	6565	8218	7492
yield wheat straw (kg/ha)	3985	3764	4510	4174
Allocation emissions to grains (-)	0.79	0.78	0.79	0.79
GHG wheat grains (g/kg)	349	339	368	375
LULUC (g/kg)	143	154	124	136
transport to feed mill in NL (g/kg)	17	20	10	30

Table 55 also shows that not all emissions are allocated to the grains (line: “ allocation emission to grains”). Because straw is (mainly) used as a bedding material, a part of the emissions is allocated to the straw. The ratio in economic revenues from grains and straw define the allocation fraction of the total emissions to the grains. The allocation figures are very similar in the countries in table countries.

Many attention is often paid to feed miles of products. In the case of wheat it is clear that the emissions from transport only play a minor role in the total GHG emissions of the grains.

9.1.3 Variation in routing of products

The advantage of the modular approach is best shown in the case of wheat (**Table 56**). Wheat can a) be used as feed directly; b) be part of a compound feed; c) be the co product wheat middlings or wheat gluten feed can be added to the animals’ ration and d) be the co product wheat middlings or wheat gluten feed can be used as part of a compound feed. In all occasions in **Table 56** the same wheat, from Germany in this example, is used. The emissions from cultivation are 349 g CO_2-equivalents per kg of wheat. In the case of the direct use as a feed material on the farm, the GHG emissions are 366 g/kg, coming from cultivation and transport to the farm. When wheat is used in a compound feed, the wheat is transported to the feed mill, also leading to 17 g CO_2-eq per kg. Processing wheat in the feed mill (grinding, mixing, pelleting) takes 49 g CO_2-eq per kg. Another 10 g CO_2-eq per kg is added for transport of the compound feed with the wheat to the farm, leading to a total emission of 425 g CO_2-eq per kg of wheat.

Table 56. The GHG emissions for cultivation, processing, compound feed production and transport for wheat used a) as feed directly; b) as part of a compound feed; c) when co products wheat middlings and wheat gluten feed are used in the animals' ration and d) when the co product wheat middlings and wheat gluten feed are used as part of a compound feed. All emissions are expressed as gram CO2-equivalents per kg of product.

	wheat		wheat in compound feed		wheat gluten feed		wheat gluten feed in compound feed		wheat middlings		wheat middlings in compound feed	
	Per stage	total	Per stage	total	Per stage	total	Per stage	total	Per stage	total	Per stage	total
cultivation	349		349		349	349	349	349	349		349	
transport to process					38		38		38		38	
Allocation factor					*2.81*		*2.81*		*0.53*		*0.53*	
from cultivation (after allocation)					983		983		184		184	
From transport (after allocation)					108		108		20		20	
processing					1086		1086		26		26	
end of processing						2177		2177		230		230
transport to feed mill			17		0		17		0		17	
feed mill			49		0		49		0		49	
end of feed mill				415				2243				296
transport to farm	17		10		17		10		17		10	
animals' ration		366		425		2194		2253		247		306

When wheat is dry milled, the co-product middlings has lower GHG emissions per kg, due to the lower economic value of this product. At the end of the processing stage the GHG emissions of middlings are 230 g CO_2-eq per kg. After processing the steps are similar to wheat. Using the middlings directly in a ration, an extra 17 g CO_2-eq is added for transport, when middlings are part of a compound feed, (17 + 49 + 10 =)76 g CO_2-eq are added. The total emissions for middlings are 247 CO_2-eq as single feed or 306 g CO_2-eq per kg as part of a compound feed.

In the case of wet milling the wheat gluten feed has a higher economic value, compared to other co products, which leads to an allocation factor of 2.18, indicating that upstream emissions are multiplied by 2.18. After wet milling co products are dried, except the wheat starch slurry. Drying has a high energy requirement and high CO_2 emissions. The combination of the high allocation of upstream emissions to wheat gluten feed and the high energy requirements for drying leads to ten times higher emissions for wheat gluten feed, compared to wheat middlings. Using the gluten feed directly in a ration, or as part of a compound feed, adds another 17 and 76 g CO_2-eq to the ingredients, respectively. The total emissions for gluten feed as single feed or as part of a compound feed are 2194 and 2253 g CO_2-eq per kg, respectively.

The higher GHG emissions when wheat, middlings or gluten feed are part of a compound feed are caused by extra transport and the milling process. It might give the impression that using single components and mixing them to a balanced ration is a good mitigation option. In part this can be the case. However, in this case grinding and mixing will be done at the farm instead of the feed mill and energy requirements are only shifting from one location to another. Only one extra transport can be omitted, leading to a reduction of 10 gram CO_2-eq per kg.

The figures in this example show the advantage of the modular approach, providing maximum flexibility in the calculation of GHG emissions for feed materials. The standardisation in transport distances is supporting the flexibility as well.

9.2 The impact of different ways of allocation to co-products

Economic allocation is the preferred methodology in FeedPrint. The allocation method has been applied as precise as possible being consistent for all processes. If possible the allocation took place on sub process level, to exclusively allocate the energy and other inputs to the specific feed material. For practical reasons, in most cases, a zero price of the wet co-product is assumed at the moment of appearance. For a group of feed materials, especially those that have an intensive drying step involved, the resulting GHG values may deviate considerably from values previously published based on Input/Output data of industries. In section 9.2.1 an overview will be presented of the differences between the I/O data method and the detailed allocation and the impact of setting the price at null for some cases will be shown.

In section 9.2.2 the differences in GHG emissions by different allocation methods, such as mass or energy based allocation, will be explored. Results are compared with economic allocation as the baseline method, The FeedPrint tool offers the possibility to apply other allocation methods, allowing to study the sensitivity of results in relation to allocation choices.

9.2.1 Consequences of applying residue allocation instead of overall input/output based economic allocation

For many feed materials the so called “residue allocation” method has been applied: assuming a zero price of the co product at the moment of appearance. This is also in line with the approach used in the Renewable Energy Directive (EU, 2009). However, in many previous studies on feed GHG emissions, the Input/Output based economic allocation has been applied (Blonk & Ponsioen 2009; Blonk & Kool 2009, Blonk et al. 2011). Table 57 shows the impact on the GHG emissions of the FeedPrint method for some often used feed materials.

Table 57. The GHG emissions (CO2-equivalents in g/kg product) of dried beet pulp, citrus pulp and whey powder calculated according the Input/Output economic allocation and according the FeedPrint approach, applying residue allocation. Data from Blonk & Ponsioen 2009; Blonk & Kool 2009, Blonk et al. 2011 and FeedPrint.

Raw material	GHG emission according to using I/O economic allocation (kg/kg)	GHG emission according to FeedPrint, applying residue allocation (kg/kg)
Dried Beet pulp from NL	100	292
Dried Citrus pulp from Brazil	300	624
Whey powder from NL	1900	529

As can be seen in Table 57, the change in GHG emissions is considerable, up to a factor 3, for dried beet pulp, however the direction of the change may differ between products. In case of dried beet pulp and dried citrus Pulp the FeedPrint economic allocation method calculates higher emissions compared to the I/O method. Here the specific energy use for drying is much higher than the share of the upstream lifecycle GHG emissions that would have been allocated to the feed material on the basis of the relative share of the product in the overall revenues of the sold products on plant level. For whey powder it works the other way around. Here the lifecycle upstream emissions of the production of milk at farm are relatively high in comparison to the energy use for drying.

In FeedPrint we simplified economic allocation in those cases where the relative value of a product in its wet form has a low fraction (less than 5%) in the overall revenue of the company. If we would take the upstream emissions into account the GHG emission score for dried beet pulp would have been 5% higher, 305 instead of 292 g CO2-equivalents per kg. For dried citrus pulp we cannot make this comparison, due to the lack of price information of the wet product.

9.2.2 Impact of alternative allocation methods

The FeedPrint tool allows to apply different allocation methods. As argued in the phase 1 document (Blonk et al.. 2009) this is an important feature, since the differences between different allocation methods can be considerable depending on the feed material (see Figure 15).

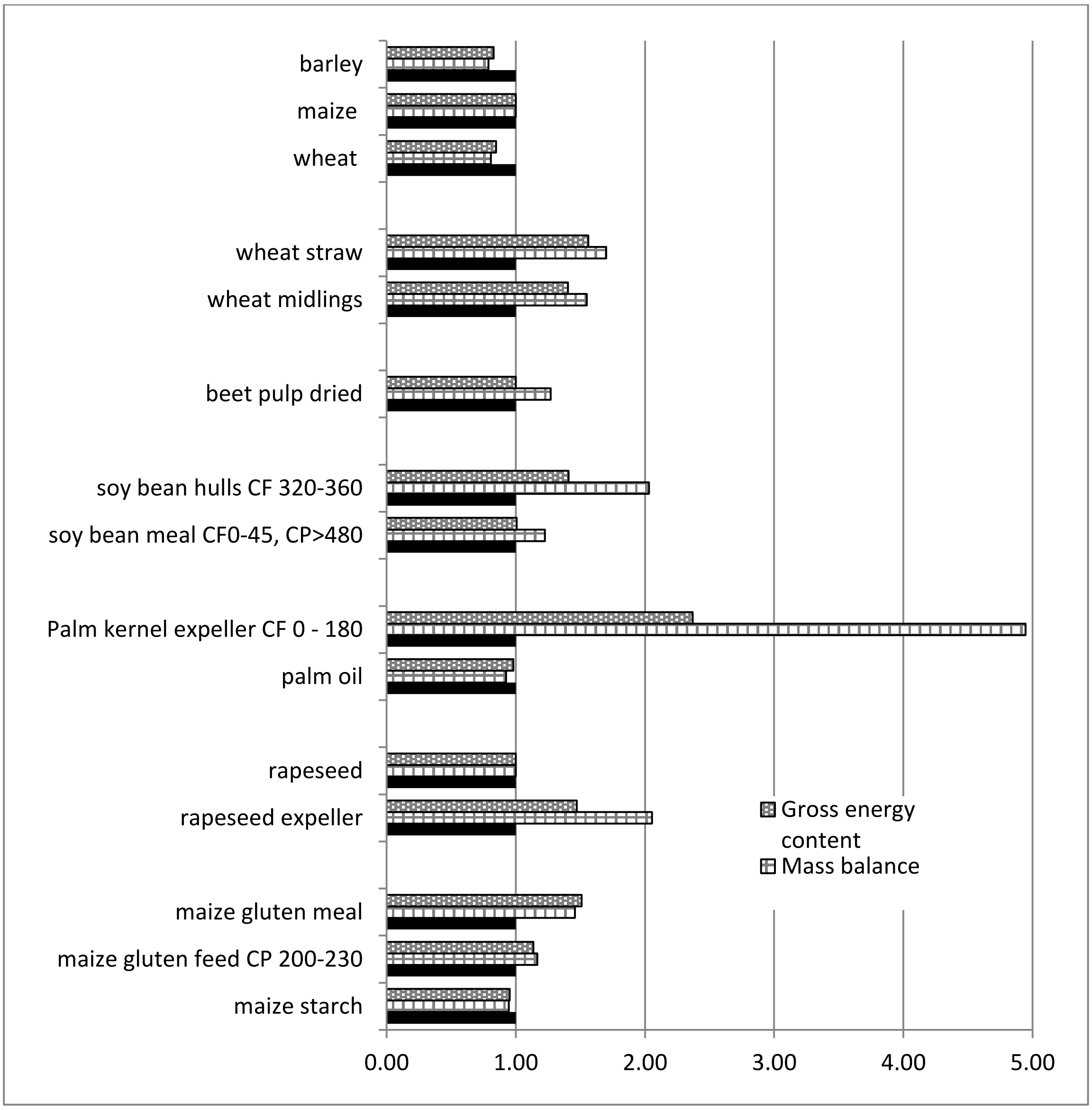


Figure 15 The impact of different allocation methods on GHG emission values per feed material (the GHG emission in case of economic allocation is set at 1, other values are relative to economic allocation, and excluding LUC). Data coming from FeedPrint.

Emissions for barley and wheat are lower with mass and gross energy allocation, caused by the fact that a larger part of the emissions is allocated to the straw. Without an alternative use for straw, as is the case with maize, in fact no allocation is applied and emissions do not change.

The mass and gross energy allocation lead to reduced GHG emissions for grains as wheat and barley, but at the same moment, increased emission for co products such as straw and middlings do occur.

In the case of wet co-products, gross energy allocation and economic allocation give the same emissions, because the wet co products are considered as a residue. In the case of mass allocation, upstream emissions of cultivation and processing are allocated to the co-products and calculated emissions are higher.

In the case of the co products with a lower economic value, but similar gross energy contents compared to the other co products such as maize gluten meal, soy bean hulls, rapeseed expeller, the allocation on the basis of gross energy will lead to an increase of 40 – 50 % and the allocation on the basis of mass even to increases of 50 – 100 %. The same pattern can be seen for maize gluten feed and soy bean meal.

Palm kernel is very strong affected by the type of allocation. Gross energy allocation increase the GHG emissions by 230 %, whereas mass allocation leads to 500 % increase.

The impact on the carbon footprint on compound feed level seems to be the highest for dairy feed (see Figure 16). This is caused by the relatively large fraction of co-products in the feed. It must be stressed however that the calculations are made for a realistic sample feed, with a composition representative for a certain time period. The strong effect of allocation method on the dairy compound feeds is caused by the large fraction of palm kernel expeller. The composition of compound feeds varies over time, which can have a big impact on GHG emissions scores (Blonk and Kool 2009).

It can be concluded that the type of allocation has clear effects on the calculated GHG emissions for co products.

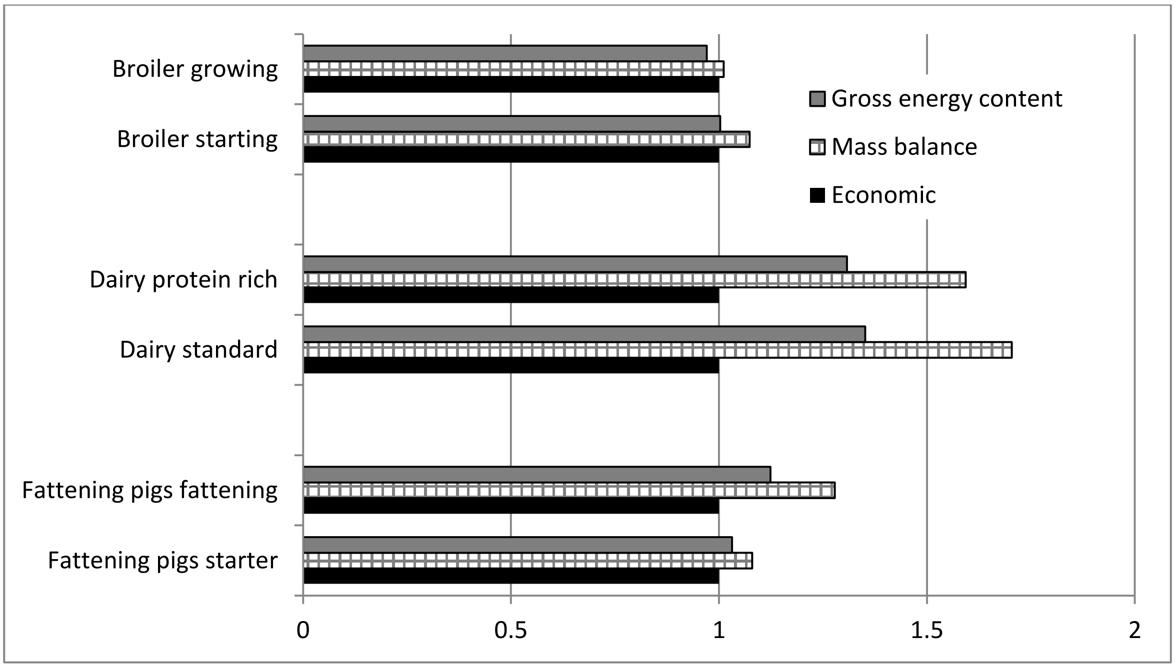


Figure 16 Impact of different allocation methods on GHG emission values of examples of compound feeds (the GHG emission in case of economic allocation is set at 1, other values are relative to economic allocation, and excluding LUC). Data coming from FeedPrint.

9.3 Land Use Change

In the public discussion, land use change is strongly related to Brazilian soy and South-East Asian palm fruit (e.g. Audsley et al.., 2010)). In our approach, emissions from land use change are attributed to all hectares of agricultural land on a global scale, based on the idea that land can only be used once and that the choice of a certain crop excludes the growth of another one. GHG emissions from LUC are 1180 kg CO_2-equivalents per hectare (Chapter 4.7). As a consequence, the emissions depend on the yield per hectare. In the examples in **Table 58**, LUC emissions from French wheat are 141 g/kg CO_2-eq, caused by the relatively high yield compared to soy bean and rape seed and by an allocation of 21 % of the emissions to the straw. The yield of rape seed is about 50 % higher than soybean, and LUC emissions are about two third (= 1/1.5) of that of soy bean. The high yield of palm fruit in Malaysia causes a relatively low LUC emission of 55 g/kg CO_2-eq. The high cultivation emissions of the palm fruit are caused by the high emissions from cultivation of peat soil and the large fraction of crop co products that are returned to the fields.
A similar approach has been chosen by Audsley et al.. (2010), limiting LUC emissions to commercial agriculture only. They calculate 1430 kg CO_2-equivalents per hectare, leading to 21 % higher LUC emissions compared to FeedPrint.In other studies, using a different approach completely different LUC emissions have been found. FAO (2010) only considers soy beans and calculates 7.69 kg CO_2-equivalents for 1 kg of soy beans from Brazil and 0.93 kg CO_2-equivalents for 1 kg of soy beans from Argentina. The difference between both countries comes from the shift from mainly tropical forest to arable land in Brazil and from mainly natural grassland to cropland in Argentina. In the FAO report (2010), no LUC emissions have been attributed to other crops. Leip et al.. (2010) calculate LUC emissions on the basis of land use change dynamics caused by European livestock production. Their approach also leads to LUC emissions for European crops, although with lower values compared to FeedPrint and Audsley et al.. (2010). LUC emissions from soybeans are higher, caused by considering land use dynamics in non-European countries.

Table 58. Comparison of land use change emissions of FeedPrint with other methods.

	Wheat France	Soy bean Brazil	Rape seed Germany	Palm fruit Malaysia
N input organic manure (kg/ha)	29	41	62	27
N input synthetic fertilizer (kg/ha)	119	3	200	130
yield main product (kg/ha)	6565	2442	3610	21300
yield co product (kg/ha)	3764	0	0	0
Allocation emissions to main product (-)	0.78	1	1	1
GHG main product (g/kg)	337	477	1032	604
Land Use Change emissions				
FeedPrint (based on 1180 kg/ha) (g/kg)	141	483	327	55
Audsley et al.. (2010) (1430 kg/ha)* (g/kg)	171	585	396	67
FAO (2010) (g/kg)	0	7690	0	-
Leip et al.. (2010) (g/kg)	35	1099 – 1207	153	-

*: the emissions by Audsley et al.. (2010) have been calculated on the basis of the yields in FeedPrint and the emission of 1430 kg CO_2-equivalents per hectare.

9.4 Uncertainty analysis

The Monte Carlo simulation in FeedPrint is used to calculate the confidence interval at the level animal's rations and output. This is the result of mean, variation and distributions types of all individual foreground data contributing to the GHG emissions of feed components. A list of parameters that were simulated is given in **Table 59** and **Table 60**. Other parameters were taken as constants by using their values as mean.

Table 59. List of parameters that were simulated in the Monte Carlo calculations using data.

Stage	Group	Parameters
Cultivation	Soil characteristics	Soil peat
	Plant material	Seed amount
	Organic fertilisation	N amount
	Artificial fertilisation	N amount
	Artificial fertilisation	P amount
	Artificial fertilisation	K amount
	Artificial fertilisation	Lime amount
	Pesticide use	Active ingredient amount
	Crop residue	Residue amount
	Crop residue	Slope of yield vs crop residue amount
	Crop residue	Intercept of yield vs crop residue amount
	Crop residue	Below/Above Ground ratio
	Crop residue	Nitrogen content above ground
	Crop residue	Nitrogen content below ground
	Crop yield	Product yield amount
	Crop storage energy	All individual energy carriers
Processing	Auxiliary compounds	Auxiliary amount
	Energy input	All individual energy carriers
Machine use	Energy input	Via land area = Amount necessary / crop yield

Table 60. Parameters that were simulated in the Monte Carlo calculations with hard-coded distribution values

Stage	Parameter	Hardcoded distribution
Cultivation (per ha)	Land use change*	LUC ϵ $[0, 2\cdot(1180\text{-}47)]$
	Land use Grassland CO_2*	$LUgrassCO_2$ ϵ $[-2\cdot 47\cdot 44/12, 0]$
	Land use Grassland N_2O*	$LUgrassN_2O$ ϵ $[0, 2\cdot 0.38\cdot 44/28]$
	Land use Arable land CO_2*	$LUarableCO_2$ ϵ $[0, 2\cdot 30\cdot 44/12]$
	Land use Arable land N_2O*	$LUarableN_2O$ ϵ $[0, 2\cdot 0.03975\cdot 44/28]$
Transport (per 1000km)	Sea ship**	μ= Midpoint distance CO_2 emission, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$
	Plane**	μ= Midpoint distance CO_2 emission, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$
	Other**	μ= Midpoint distance CO_2 emission, $2\cdot\sigma = 2\cdot\sqrt{(0.25\cdot\mu)}$
Production Farm	Animal products	μ= CO_2 emission/kg animal product, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$
	Manure	μ= CH_4 emission/kg manure, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$
	Fermentation	μ= CH_4 emission/kg manure, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$
	Manure storage	μ= CO_2 emission/kg manure, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$
	Manure storage	μ= CH_4 emission/kg manure, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$
	Manure storage	μ= N_2O emission/kg manure, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$
	Manure application	μ= CO_2 emission/kg manure, $2\cdot\sigma = 2\cdot\sqrt{(0.1\cdot\mu)}$

* Uniform distribution
** Normal distribution

The calculated mean values obtained from the Monte Carlo simulation allow localisation of potential hot spots, yet it is the standard deviation of a parameter that defines the sensitivity of the calculated value to changes of said parameter. The sensitivity analyses of the standard feed rations used in FeedPrint have been calculated and put into tornado diagrams. Besides a numerical representation of the calculated carbon dioxide footprint, these diagrams show the possible influence of each stage as a horizontal bar.

Figure 17 shows the sensitivity analysis for the Dairy standard ration used in FeedPrint. Both processing and crop inputs can influence the calculated value of 174.1 g CO_2e/kg in almost equal amounts. Potential mitigation contributions from changes in machine use, transport, storage and feed mill are of minor concern. Sensitivity to the processing stage is explained by the need of processing energy required for the formulation of the feed for the young animals.

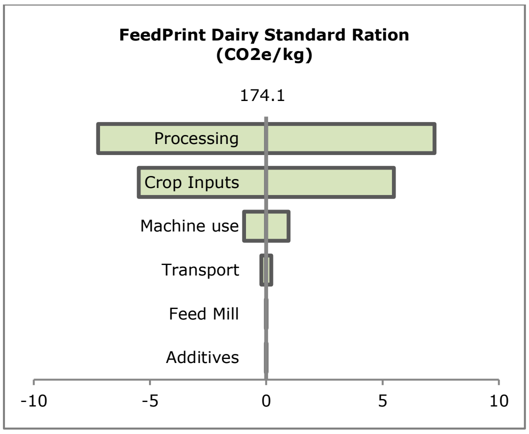


Figure 17. The uncertainty range around the average GHG emissions (g CO2-eq/kg) of the standard dairy ration in FeedPrint. The horizontal bars show the contribution to the uncertainty range for the different stages in the production chain.

The sensitivity analysis of the veal feed rations in FeedPrint (Figure 18) shows that the processing stage has a large influence on the uncertainty of the calculated carbon footprint per kg feed ration. Mind that the scale of the horizontal axis is not the same for all graphs.The milk replacers used consist for more than 80 % of animal products, hence the contribution of crops to uncertainty is very limited. The comparison of the milk-fed and rose veal production in Figure 18 respectively, reveals that the processing stage of the ration for milk-fed veal has a much bigger potential influence on the carbon footprint than in the ration for rose veal. This can be explained by the fact that the ration of rose veal contains relatively more maize, which leads to a lower overall carbon footprint per kg feed, a lowered influence of processing emissions related to milk products fed, and a slightly increased influence of crop inputs on the calculated carbon footprint.

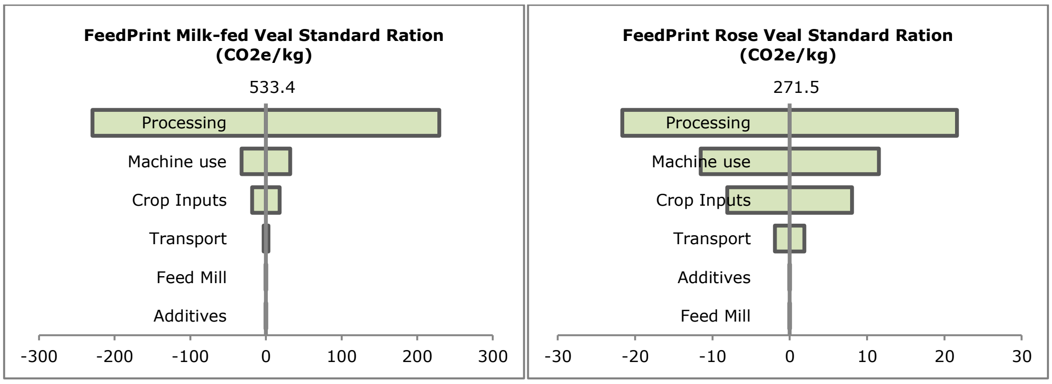


Figure 18 The uncertainty range around the average GHG emissions (g CO2-eq/kg) of the standard rations for milk-fed veal (left hand graph) and rose veal (right hand graph) in FeedPrint. The horizontal bars show the contribution to the uncertainty range for the different stages in the production chain.

A completely different picture is obtained in the sensitivity analysis of the feed rations used for pigs and breeding sows(Figure 19). The footprint of crop inputs, and to a lesser extent the related machine use, are more pronounced in this case. The larger influence of the cultivation stage and especially the crop inputs, compared to the veal rations is caused by the much larger fraction of co-products from plant production. The larger contribution of processing to uncertainty in the case of breeding sows is caused by the larger fraction of processed co-products, compared to the compound feed of fattening pigs.

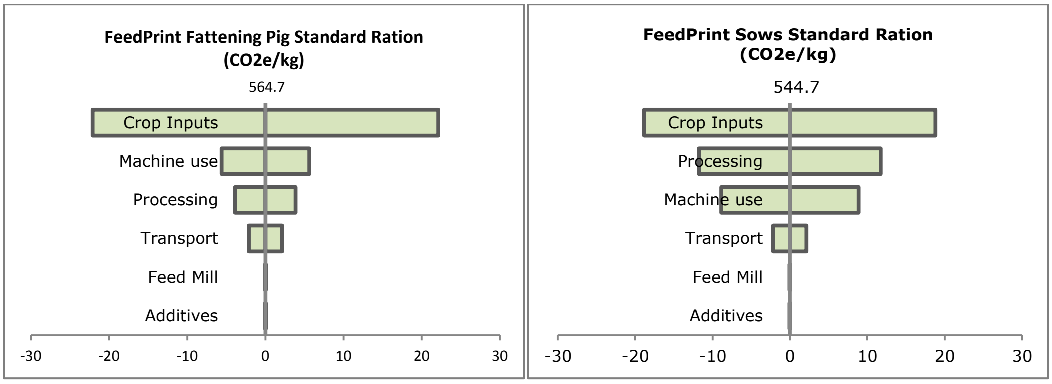


Figure 19. The uncertainty range around the average GHG emissions (g CO2-eq/kg) of the standard rations for fattening pigs (left hand graph) and breeding sows (right hand graph) in FeedPrint. The horizontal bars show the contribution to the uncertainty range for the different stages in the production chain.

Similar effects as with pigs can be seen in the chicken rations (Figure 20), also mainly consisting of products from plant origin. The limited contribution of processing to the uncertainty is caused by the lower contents of processed co products and the higher contents of primary products, compared to the pig rations.

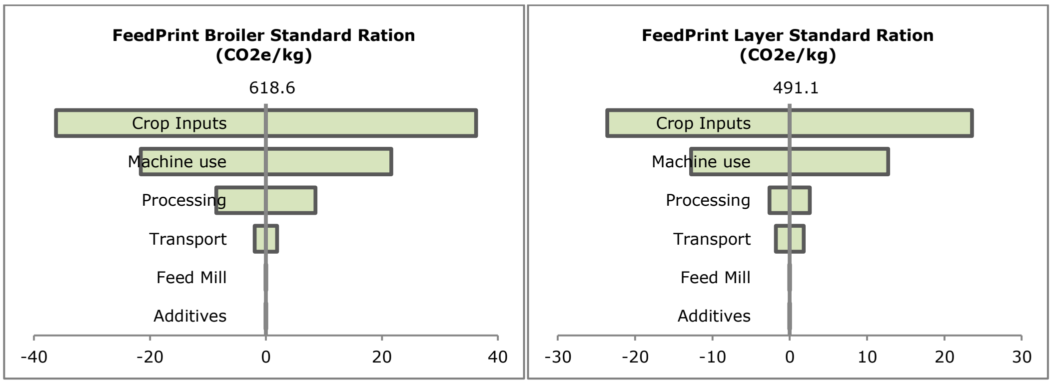


Figure 20 The uncertainty range around the average GHG emissions of the standard rations for broilers (left hand graph) and layers (right hand graph) in FeedPrint. The horizontal bars show the contribution to the uncertainty range for the different stages in the production chain.

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Appendices

Appendix 1 Feed materials of plant origin

CvbCod	NamUK	Crop/Animal/Remark	Process/Industry
822	Urea	additive	
948	DL-Methionine	additive, no GHG assessed	
915	Fytase 1 (max. 0,2%)	additive, no GHG assessed	
922	Fytase 1 m2346 (max. 0,2%)	additive, no GHG assessed	
916	Fytase 2 (max.0,45%)	additive, no GHG assessed	
923	Fytase 2 m2346 (max. 0,45%)	additive, no GHG assessed	
911	Kalksteentjes	additive, no GHG assessed	
910	Krijt (fijn gemalen)	additive, no GHG assessed	
949	L-Isoleucine	additive, no GHG assessed	
945	L-Lysine HCL	additive, no GHG assessed	
946	L-Threonine	additive, no GHG assessed	
947	L-Tryptofaan	additive, no GHG assessed	
918	Magnesiumoxide	additive, no GHG assessed	
971	Mervit Opfok 2849	additive, no GHG assessed	
912	Monocalciumfosfaat	additive, no GHG assessed	
914	Natrium-Bicarbonaat	additive, no GHG assessed	
937	Premix Melkvee 31	additive, no GHG assessed	
938	Premix Vleesvee 45	additive, no GHG assessed	
846	Soycomill	additive, no GHG assessed	not applicable
972	Zeezand gedroogd	additive, no GHG assessed	
913	Zout	additive, no GHG assessed	
16400	Barley	Barley	unprocessed
16800	Barley feed h grade	Barley	dry milling
16500	Barley mill byprod	Barley	dry milling
18100	Barley straw	Barley	unprocessed
17410	Brewers grains 22% Dry Matter	Barley	Brewery
67200	Brewers grains 27% DM	Barley	Brewery
17100	Brewers' grains dried	Barley	Brewery
17210	Malt culms Crude Protein<200	Barley	Brewery
17220	Malt culms Crude Protein>200	Barley	Brewery
54300	Bean straw (Phas)	bean	unprocessed
54400	Bean straw (Vicia)	bean	unprocessed
22300	Beans phas heat treated	bean	Heat treating of beans
39700	Field beans silage	bean	unprocessed
22400	Horsebeans	bean	unprocessed
26100	Horsebeans white	bean	unprocessed
10000	Buckwheat	buckwheat	unprocessed
20000	Canaryseed	canary seed	unprocessed
39610	Tapioca STA 575-625	Cassava	wet milling
39620	Tapioca STA 625-675	Cassava	wet milling

39630	Tapioca STA 675-725	Cassava	wet milling
39400	Tapioca starch	Cassava	wet milling
86400	Green cereals fresh	cereals	roughage
86500	Green cereals silage	cereals	roughage
41600	Whole crop silage(Cereals)	cereals	roughage
76800	Chicory leaves fresh	chicory	inulin industry
76900	Chicory leaves sil	chicory	inulin industry
65700	Chicory pulp dried	chicory	inulin industry
64200	Chicory pulp f+sil	chicory	inulin industry
41810	Chicory rts frcd cl	chicory	inulin industry
41820	Chicory rts frcd di	chicory	inulin industry
41700	Chicory rts not frcd	chicory	inulin industry
62800	Clover red ad	clover	roughage
73300	Clover red fresh	clover	roughage
86600	Clover red hay	clover	roughage
39800	Clover red sil	clover	roughage
54700	Clover red straw	clover	roughage
32310	Coconut expeller Crude FAT<100	Coconut	crushing
32320	Coconut expeller Crude FAT>100	Coconut	crushing
32400	Coconut extruded	Coconut	solvent extraction
13100	Dist grains and solubles fresh	corn	Bio-ethanol
11800	Maize bran	corn	dry milling
14400	Maize chemical heat treated	corn	chemical heat treatment
11700	Maize feed meal	corn	dry milling
13300	Maize feed meal extruded	corn	dry milling
11600	Maize feedflour	corn	dry milling
13700	Maize germ m fd extruded	corn	wet milling
13500	Maize germ meal extruded	corn	wet milling
13600	Maize germ meal feed expeller	corn	wet milling
12510	Maize gluten feed Crude Protein<200	corn	wet milling
12530	Maize gluten feed Crude Protein>230	corn	wet milling
12520	Maize gluten feed Cude Protein 200-230	corn	wet milling
12400	Maize gluten meal	corn	wet milling
14300	Maize glutenfeed fresh+sillage	corn	wet milling
12600	Maize solubles	corn	wet milling
12300	Maize starch	corn	wet milling
33220	Cottonseed expeller p with husk	cotton	crushing
33230	Cottonseed expeller with husk	cotton	crushing
33210	Cottonseed expeller without husk	cotton	crushing
33520	Cottonseed extruded partly with husk	cotton	solvent extraction
33530	Cottonseed extruded with husk	cotton	solvent extraction
33510	Cottonseed extruded without husk	cotton	solvent extraction
33020	Cottonseed with husk	cotton	crushing
33010	Cottonseed without husk	cotton	crushing
38520	Fodderbeets cleaned	fodder beet	unprocessed

38510	Fodderbeets dirty	fodder beet	unprocessed
85980	Grass average	grass	unprocessed
59800	Grass bales ad	grass	unprocessed
85912	Grass fr April h y.	grass	unprocessed
85910	Grass fr April l y.	grass	unprocessed
85911	Grass fr April n y.	grass	unprocessed
85952	Grass fr Aug h y.	grass	unprocessed
85950	Grass fr Aug l y.	grass	unprocessed
85951	Grass fr Aug n y.	grass	unprocessed
85942	Grass fr July h y.	grass	unprocessed
85940	Grass fr July l y.	grass	unprocessed
85941	Grass fr July n y.	grass	unprocessed
85932	Grass fr June h y.	grass	unprocessed
85930	Grass fr June l y.	grass	unprocessed
85931	Grass fr June n y.	grass	unprocessed
85922	Grass fr May h y.	grass	unprocessed
85920	Grass fr May l y.	grass	unprocessed
85921	Grass fr May n y.	grass	unprocessed
85972	Grass fr Oct h y.	grass	unprocessed
85970	Grass fr Oct l y.	grass	unprocessed
85971	Grass fr Oct n y.	grass	unprocessed
85962	Grass fr Sept h y.	grass	unprocessed
85960	Grass fr Sept l y.	grass	unprocessed
85961	Grass fr Sept n y.	grass	unprocessed
40720	Grass hay av qual	grass	unprocessed
40730	Grass hay good qual	grass	unprocessed
40742	Grass hay horse crs	grass	unprocessed
40740	Grass hay horse fine	grass	unprocessed
40741	Grass hay horse midd	grass	unprocessed
40710	Grass hay poor qual	grass	unprocessed
85990	Grass horse gr past	grass	unprocessed
85991	Grass horse same fld	grass	unprocessed
40810	Grass meal Crude Protein<140	grass	Articicial drying grass and lucerne
40840	Grass meal Crude Protein>200	grass	Articicial drying grass and lucerne
40820	Grass meal Crude Protein140-160	grass	Articicial drying grass and lucerne
40830	Grass meal Crude Protein160-200	grass	Articicial drying grass and lucerne
43600	Grass seeds	grass	unprocessed
54500	Grass seeds straw	grass	unprocessed
86050	Grass sil average	grass	unprocessed
86062	Grass sil horse crs	grass	unprocessed
86060	Grass sil horse fine	grass	unprocessed
86061	Grass sil horse midd	grass	unprocessed
86030	Grass sil Ju-Au 2000	grass	unprocessed

86031	Grass sil Ju-Au 3000	grass	unprocessed
86032	Grass sil Ju-Au 4000	grass	unprocessed
86020	Grass sil June 2000	grass	unprocessed
86021	Grass sil June 3000	grass	unprocessed
86022	Grass sil June 4000	grass	unprocessed
86010	Grass sil May 2000	grass	unprocessed
86011	Grass sil May 3500	grass	unprocessed
86012	Grass sil May 5000	grass	unprocessed
86040	Grass sil Se-Oc 2000	grass	unprocessed
86041	Grass sil Se-Oc 3000	grass	unprocessed
31900	Hempseed	hemp	crushing
23500	Lentils	lentils	unprocessed
28500	Linseed	linseed	unprocessed
28600	Linseed expeller	linseed	crushing
28700	Linseed extruded	linseed	crushing
40010	Alf meal Crude Protein<140	Lucerne	Articicial drying grass and lucerne
40040	Alf meal Crude Protein>180	Lucerne	Articicial drying grass and lucerne
40020	Alf meal Crude Protein140-160	Lucerne	Articicial drying grass and lucerne
40030	Alf meal Crude Protein160-180	Lucerne	Articicial drying grass and lucerne
67700	Lucerne (alfalfa) ad	Lucerne	unprocessed
39900	Lucerne fresh	Lucerne	unprocessed
63300	Lucerne hay	Lucerne	unprocessed
62900	Lucerne sil	Lucerne	unprocessed
22710	Lupins Crude Protein<335	lupines	unprocessed
22720	Lupins Crude Protein>335	lupines	unprocessed
14220	corn cob mix Crude Fiber 40-60	maize	unprocessed
14210	corn cob mix Crude Fiber<40	maize	unprocessed
14230	corn cob mix Crude Fiber>60	maize	unprocessed
11200	Maize	maize	unprocessed
92700	Maize (Fodder) silage	maize	unprocessed
53200	Maize Cron Cob Mix sillage	maize	unprocessed
53140	Maize fodder fresh Dry Matter 320	maize	unprocessed
53110	Maize fodder fresh Dry Matter<240	maize	unprocessed
53120	Maize fodder fresh Dry Matter240-280	maize	unprocessed
53130	Maize fodder fresh Dry Matter280-320	maize	unprocessed
40410	Maize sil Dry Matter < 240	maize	unprocessed
40440	Maize sil Dry Matter > 320	maize	unprocessed
40420	Maize sil Dry Matter 240-280	maize	unprocessed
40430	Maize sil Dry Matter 280-320	maize	unprocessed
18300	Millet	millet	unprocessed
65100	Millet pearlmillet	millet	unprocessed
26600	Nigerseed	niger seed	unprocessed
56000	Biscuits Crude FAT<120	no crop	Bread meal

56200	Biscuits Crude FAT>120	no crop	Bread meal
21900	Bread meal	no crop	Bread meal
48320	Brewers yeast Crude Protein 400-500	no crop	Brewery
48310	Brewers yeast Crude Protein<400	no crop	Brewery
48330	Brewers yeast Crude Protein>500	no crop	Brewery
48400	Brewers' yeast dried	no crop	Brewery
54600	Oat straw	oats	unprocessed
15400	Oats grain	oats	unprocessed
16100	Oats grain peeled	oats	dry milling
16000	Oats husk meal	oats	dry milling
15600	Oats mill feed h grade	oats	dry milling
32500	Macoya fruit expeller	oil palm	crushing
26410	Palm kern expeller Crude Fiber <180	oil palm	crushing
26420	Palm kern expeller Crude Fiber>180	oil palm	crushing
26500	Palm kernel extruded	oil palm	solvent extraction
26300	Palm kernels	oil palm	solvent extraction
848	Palm oil	oil palm	crushing
66300	Fats/oils vegetable	oil seeds and oil fruits	crushing
26200	Fats/oils vegetable h %d	oil seeds and oil fruits	crushing
42100	Citrus pulp dried	Oranges	Citrus pulp drying
40300	Pea haulm fresh	pea	unprocessed
40200	Pea haulm sil	pea	unprocessed
40100	Pea straw	pea	unprocessed
24420	Peanut expeller partly with shell	Peanuts	crushing
24430	Peanut expeller with shell	Peanuts	crushing
24410	Peanut expeller without shell	Peanuts	crushing
24720	Peanut extruded with shell	Peanuts	solvent extraction
24710	Peanut extruded without shell	Peanuts	solvent extraction
24120	Peanuts with shell	Peanuts	unprocessed
24110	Peanuts without shell	Peanuts	unprocessed
22900	Peas	peas	unprocessed
28900	Poppyseed	poppy seed	unprocessed
65800	Potato crisps	potatoes for human consumption	potato processing
36300	Potato cut raw	potatoes for human consumption	potato processing
36410	Potato cuttings Crude Fat 40-120	potatoes for human consumption	potato processing
36430	Potato cuttings Crude Fat>180	potatoes for human consumption	potato processing
36420	Potato cuttings Crude Fat120-180	potatoes for human consumption	potato processing
36510	Potato peelings starch STA<350	potatoes for human consumption	potato processing
36540	Potato peelings starch STA>600	potatoes for human consumption	potato processing
36520	Potato peelings starch STA350-475	potatoes for human consumption	potato processing
36530	Potato peelings starch STA475-600	potatoes for human consumption	potato processing
77230	Potato starch gel STA 550-675	potatoes for human consumption	potato processing
79800	Potato starch heat treated	potatoes for human consumption	potato processing
77210	Potatoe starch gel STA 300-425	potatoes for human consumption	potato processing
77220	Potatoe starch gel STA 425-550	potatoes for human consumption	potato processing

77240	Potatoe starch gel STA>675	potatoes for human consumption	potato processing
35310	Potatoe starch STA 500-650	potatoes for human consumption	potato processing
35320	Potatoe starch STA 650-775	potatoes for human consumption	potato processing
35330	Potatoe starch STA>750	potatoes for human consumption	potato processing
36000	Potatoes dried	potatoes for human consumption	potato processing
34620	Potatoes fresh	potatoes for human consumption	potato processing
35900	Potatoes sil	potatoes for human consumption	potato processing
76300	Potato-peelings sil	potatoes for human consumption	potato processing
48200	Rapes meal Mervobest	Rapeseed	solvent extraction & formaldehyde treatment
29600	Rapeseed	Rapeseed	unprocessed
29700	Rapeseed expeller	Rapeseed	crushing
29810	Rapeseed extruded Crude Protein<380	Rapeseed	solvent extraction
29820	Rapeseed extruded Crude Protein>380	Rapeseed	solvent extraction
15200	Rice bran meal extruded	rice	dry milling
17010	Rice feed meal ASH<90	rice	dry milling
17020	Rice feed meal ASH>90	rice	dry milling
14700	Rice husk meal	rice	dry milling
14520	Rice with hulls	rice	dry milling
14510	Rice without hulls	rice	dry milling
18700	Rye	rye	unprocessed
19100	Rye middlings	rye	dry milling
54800	Rye straw	rye	unprocessed
31800	Safflower meal extruded	safflower seed	crushing
31500	Safflowerseed	safflower seed	unprocessed
28200	Sesame seed	sesame seed	unprocessed
28300	Sesame seed expeller	sesame seed	crushing
28400	Sesame seed meal extruded	sesame seed	solvent extraction
19400	Sorghum	sorghum	unprocessed
19600	Sorghum gluten meal	sorghum	wet milling
30800	Soy bean expeller	soy beans	crushing
31010	Soy bean hulls Crude Fiber<320	soy beans	solvent extraction
31030	soy bean hulls Crude Fiber>360	soy beans	solvent extraction
31020	soy bean hulls Crude Fiber320-360	soy beans	solvent extraction
30919	Soy bean meal Crude Fiber<45 Crude Protein>480	soy beans	solvent extraction
30910	Soy bean meal Crude Fiber < 50	soy beans	solvent extraction
30911	soy bean meal Crude Fiber<45 Crude Protein<480	soy beans	solvent extraction
30912	soy bean meal Crude Fiber<45 Crude Protein>480	soy beans	solvent extraction
30930	Soy bean meal Crude Fiber>70	soy beans	solvent extraction
30921	soy bean meal Crude Fiber45-70 Crude Protein<450	soy beans	solvent extraction
30922	soy bean meal Crude Fiber45-70 Crude Protein>450	soy beans	solvent extraction
21400	soy bean meal Mervobest	soy beans	solvent extraction & formaldehyde treatment
38400	soy bean meal Rumi S	soy beans	solvent extraction
93000	soy bean not heat tr	soy beans	unprocessed

804	soy bean oil	soy beans	crushing
31100	soy beans heat tr	soy beans	Heat treating of beans
99999	soy protein concentrate	soy beans	crushing
35000	Potato juice conc	starch potato	wet milling
34910	Potato protein ASH<10	starch potato	wet milling
34920	Potato protein ASH>10	starch potato	wet milling
34810	Potato pulp Crude Protein<95	starch potato	wet milling
34820	Potato pulp Crude Protein>95	starch potato	wet milling
35500	Potato pulp pr NL	starch potato	wet milling
53600	Potato pulp pressed	starch potato	wet milling
34700	Potato starch dried	starch potato	wet milling
61300	Potato starch solid	starch potato	wet milling
38700	Beet leaves fresh	sugar beet	sugar industry
38200	Beet leaves sil	sugar beet	sugar industry
85300	Beet leaves w p beet	sugar beet	sugar industry
38000	Beet rests sililed	sugar beet	sugar industry
58500	Beetp pressed f+sil	sugar beet	sugar industry
37010	sugar beet pulp SUG<100	sugar beet	sugar industry
37040	sugar beet pulp SUG>200	sugar beet	sugar industry
37020	sugar beet pulp SUG100-150	sugar beet	sugar industry
37030	sugar beet pulp SUG150-200	sugar beet	sugar industry
36900	Sugar beets fresh	sugar beet	unprocessed
37100	Sugarbeet molasses	sugar beet	sugar industry
37610	Vinasse Sugar beet Crude Protein<250	sugar beet	Bio-ethanol
37620	Vinasse Sugar beet Crude Protein>250	sugar beet	Bio-ethanol
37200	Sugar	sugar beet and sugar cane	sugar industry
42210	sugar cane molasse SUG<475	sugar cane	sugar industry
42220	sugar cane molasse SUG>475	sugar cane	sugar industry
27210	sunflower meal Crude Fiber<160	sunflower	solvent extraction
27220	sunflower meal Crude Fiber 160-200	sunflower	solvent extraction
27230	sunflower meal Crude Fiber 200-240	sunflower	solvent extraction
27240	sunflower meal Crude Fiber>240	sunflower	solvent extraction
68400	Sunflower silage	sunflower	unprocessed
26910	Sunflowers dehulled	sunflower	crushing
27110	sunflowers expeller dehulled	sunflower	crushing
27120	sunflowers expeller partly dehulled	sunflower	crushing
27130	sunflowers expeller with hulls	sunflower	crushing
26920	Sunflowers partly dehulled	sunflower	crushing
26930	Sunflowers with hulls	sunflower	crushing
39300	Potatoes sweet dried	Sweet potatoes	unprocessed
22100	Triticale	triticale	unprocessed
65200	Apples fresh	vegetables and fruits	unprocessed
65600	Beetroot	vegetables and fruits	unprocessed
67400	Brussels sprouts	vegetables and fruits	unprocessed
41300	Brussels sprouts l&s	vegetables and fruits	unprocessed

43200	Carob	vegetables and fruits	unprocessed
52900	Carrot peelings steemed	vegetables and fruits	unprocessed
54100	Carrots	vegetables and fruits	unprocessed
80900	Cauliflower	vegetables and fruits	unprocessed
66800	Cucumber fresh	vegetables and fruits	unprocessed
82300	Endive fresh	vegetables and fruits	unprocessed
67800	Gherkin fresh	vegetables and fruits	unprocessed
63600	Kale (white-red)	vegetables and fruits	unprocessed
66900	Leeks fresh	vegetables and fruits	unprocessed
67300	Lettuce fresh	vegetables and fruits	unprocessed
86200	Marrowstem	vegetables and fruits	unprocessed
81400	Onions	vegetables and fruits	unprocessed
80800	Pears fresh	vegetables and fruits	unprocessed
81600	Spinach fresh	vegetables and fruits	unprocessed
81500	Sweet pepper fresh	vegetables and fruits	unprocessed
68700	Tomatoes fresh	vegetables and fruits	unprocessed
86300	Turnip cabbage	vegetables and fruits	unprocessed
86100	Winterrape	vegetables and fruits	unprocessed
10700	Distillers solubles fresh	wheat	Bio-ethanol
20100	Wheat	wheat	unprocessed
20700	Wheat bran	wheat	wet milling
20500	Wheat feed meal	wheat	dry milling
20410	Wheat feedflour Crude Fiber<35	wheat	dry milling
20420	Wheat feedflour Crude Fiber35-55	wheat	dry milling
20300	Wheat germ	wheat	dry milling
20800	Wheat germfeed	wheat	dry milling
21100	Wheat gluten meal	wheat	wet milling
21200	Wheat glutenfeed	wheat	wet milling
20600	Wheat middlings	wheat	dry milling
80210	Wheat starch FR STAt 300	wheat	wet milling
80010	Wheat starch STAtot 400	wheat	wet milling
59500	Wheat starch STAtot 600	wheat	wet milling
54900	Wheat straw	wheat	unprocessed

Appendix 2 Distributions

Normal
The normal distribution is the well know Gaussian curve of probability, with a central value surrounded by a 95% confidence interval, defined by plus and minus approximately two times the standard deviation. It is the most straightforward and well know distribution involving a central value and a surrounding an uncertainty range. A disadvantage within LCA analysis is the possibility of negative numbers, which might occur within the 95% interval depending on the mean value and size of standard deviation. The normal distribution is a logical choice when a best estimate or average value and insight in standard deviation is known and distribution around the mean value is assumed to be symmetric.

Parameters supplied for the database are:

- Arithmetic mean value (μ)
- Two times standard deviation (2σ)

Using the mean and the standard deviation, a 95% confidence interval can be indicated ranging from to 2.5% figure at μ - 2σ to the 97.5% figure at μ + 2σ. The mean (average) value is identical to the mode, i.e the value that appears most often.

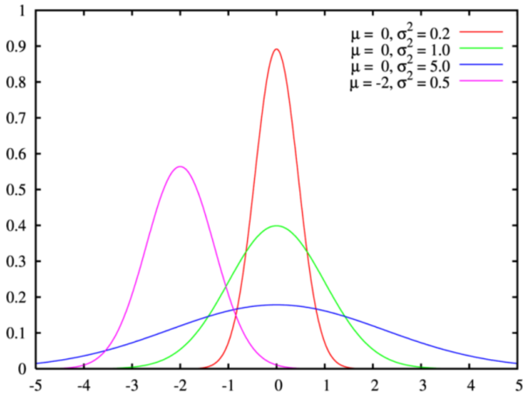

Figure YY: Examples of normal distributions with different standard deviations (source Wikipedia).

Lognormal
The lognormal distribution is based on a normal distribution of the underlying data in logarithmic form. The lognormal distribution has the advantage of excluding negative numbers by default. The distribution is slightly skewed on towards higher numbers, and (unlike a normal distribution) the actual arithmetic mean is slightly higher than the mode (geometric mean value in the lognormal distribution). The lognormal distribution is a good choice when a best estimate or average value is known, but the distribution is assumed to be asymmetric (and for example tails off to higher values).
Parameters supplied for the database are:

- Geometric mean value (μ_g)
- Square of the geometric standard deviation (σ_g^2)
- Minimum or maximum boundary to the lognormal curve
- Arithmetic mean value (calculated in database, μ)

Using the geometric mean and the square of the geometric standard deviations, a 95% confidence interval can be indicate as ranging from to 2.5% figure at μ_g / σ_g^2 to the 97.5% figure at $\mu_g * \sigma_g^2$. The minimum and maximum value are used to shift the default starting point of zero along the x-axis (see figure below). Using a maximum will invert the shape of the curve along the x-axis. It can be noted that, for small standard deviations the lognormal distribution becomes less skewed and similar to the normal distribution. The arithmetic mean is not shown as input but can be calculated from μ_g and σ_g^2.

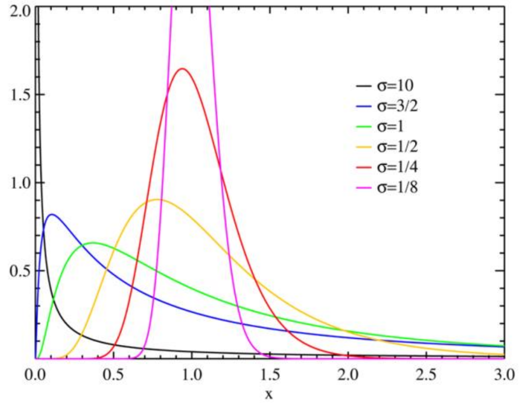

Figure YY: Examples of lognormal distributions with different standard deviations (source Wikipedia).

<u>Triangular</u>

The triangular distribution defines a hard minimum and maximum value, with a peak indicating the most likely (modal) value. This type of uncertainty distribution can be applied when a single value is considered the best estimate, but the range surrounding this value is not symmetric. The arithmetic mean value is in this case not equal to the best estimate, due to the skewedness of the triangular distribution.

Parameters supplied for the database are:

- Minimum and maximum values
- Modal value (peak of the triangle, best estimate)
- Arithmetic mean value (calculated in database, equals (minimum + maximum + modal)/3)

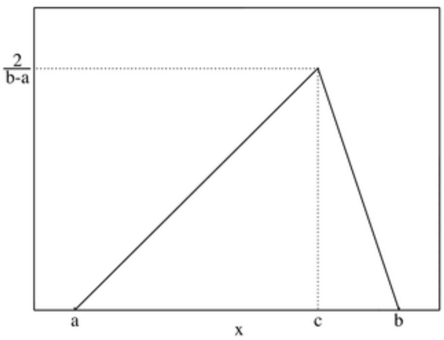

Figure YY: Example of a triangular distribution, where a and b are the minimum and maximum, and c the modal value. (source Wikipedia).

<u>Uniform</u>

When two data sources are available, with similar reliability or uncertainty, a continues uniform distribution will give a range of values between these values. All values in this range have equal probability of occurrence and the average lies precisely in between these two values.

Parameters supplied for the database are:

- Minimum and maximum values
- Arithmetic mean value (calculated in database, equals (minimum + maximum)/2)

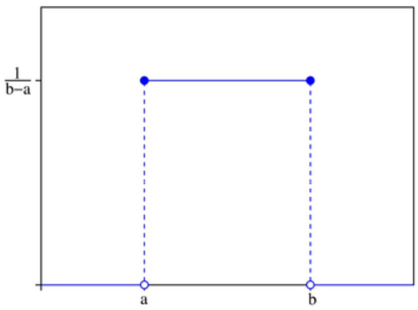

Figure YY: Example of a uniform distribution, with a and b as maximum and minimum values.

Appendix 3 Emissions of machinery use for cultivation

1 The data structure

For all crops, tractors and machinery are used for the cultivation process which includes ploughing, seedbed preparation, weed control, fertilization and harvesting.
Per crop a list of all activities must be defined, including the frequency of use . Per activity the type of machine must be defined. In a number of cases, the machines are self-propelling and do not need an external source of power, like a tractor. This is often the case with harvesting equipment and in some times with equipment for spraying pesticides or applying manure. In all other cases, tractors are required to pull the machine and to provide the power for the work done.
The data to calculate the energy use and the greenhouse gas emissions of machine use, are defined in Table 61. They are part of a set of data to calculate greenhouse gas emissions of the crop production.

Table 61. An overview of required data to calculate GHG emissions of cop production.

Process	Data	Remarks
Crop production, input data		
Production of fertilizers, pesticides	CO2 eq/kg product	
Application of fertilizers	Kg/ha	
Application of manure N	Kg/ha	
Cultivation direct energy	Use of tractors and self-propelling machines Hours/ha, Fuel use/hour	
Cultivation, indirect energy	Use of tractors, self-propelling machines and all other equipment Hours/ha MJ(energy carrier)/hour	
Crop yield	Kg product/ha	
Yield of sold crop residue	Kg product/ha	Mainly straw
Storage loss crop yield	% (kg/100 kg product)	
Energy use storage	MJ/1000 kg product	Different energy types
Emissions fertilizer application	Kg N_2O /kg N	
Emissions cultivation	CO_2eq/unit energy type	
Emissions LULUC	CO_2eq/hectare	
Emissions energy use storage	CO_2eq/MJ energy type	
Crop production, output data		
GHG emissions crop and co products	Grams/kg product (N_2O, CH_4, CO_2)	

The greenhouse gas emissions for the use of machines can be separated in direct and indirect emissions.
The direct emissions are caused by the use of fuels for the tractors or for the self-propelling machines. All equipment that is pulled by a tractor has no direct emissions. The indirect emissions are caused by the production, amortization and maintenance of all machines. The calculation of direct and indirect emissions are elaborated in chapter 3 and 0, respectively and is mainly based on the approach of Ecoinvent (2006). Ecoinvent distinguishes six categories of equipment:

1. Tractors
2. Harvesters
3. Trailers
4. Agricultural machinery, general
5. Agricultural machinery, tillage
6. Slurry tankers

These six categories are used in all calculations

2 Extrapolation of machine use

The basis for this list of activities is based on MEBOT (ref), the farm simulation model of the institute of Applied Plant Research (PPO). In the case of grass, the activities are based on the farm simulation model Dairy Wise (Schils et al.., 2007a). In the model MEBOT, activities have been defined for common crops in the Netherlands. When the same crops are grown in other countries, the same use

of equipment, tractors and self-propelling machines is assumed. Only a correction for the scale of agricultural operations is applied, when relevant. This is explained in chapter 5. A number of crops is not in the list of MEBOT. Only limited information was available on the exact use of machinery. The use of machines has been assessed in relation to the type of crop. As harvesting is a very energy consuming activity, a distinction is made between the different types of harvesting, such as the use of combined harvesters for cereals, choppers for whole plant crops and lifters for root crops. A complete list of activities for all crops is in annex x1.
Because the feed raw materials are used in large amounts, it is assumed that all crops are produced on (relatively) large scale agricultural enterprises. As a consequence, all cultivation is done by machines. No animal traction is assumed.

3 Direct energy use

Direct energy use is only calculated for tractors and for combined harvesters. Other equipment is always used in combination with a tractor. The formulas for direct energy use have been derived from Ecoinvent (2006).

Direct energy (fuel) use for tractors:

Dieseluse (a,b)	=	frequency(a) * operation time/ha(a) * MFC(a,b) * density(diesel)
Kg/ha	=	*(-) * (hr/ha) * (litres/hr) * kg/litre*
Frequency(a)	=	the frequency of the activity a in the growing season
Operation time	=	the time required to to the activity a on one hectare
MFC(a,b)	=	Mean Fuel Consumption, the characteristic fuel consumption for activity a with tractor b.
Density(diesel)	=	the density of diesel, expressed in kg per litre.
Energyuse	=	Dieseluse * energy density diesel
MJ/ha	=	(kg/ha) * (MJ/kg)
Emissions	=	Energyuse * CO2dieselMJ
Kg CO2/ha	=	MJ/ha) * kg CO2/MJ diesel
CO2dieselMJ	=	the direct and indirect greenhouse gas emissions per MJ of diesel in g/MJ

Direct energy (fuel) use for combine harvesters: (and other self-propelling equipment)

Dieseluse	=	frequency * operation time/ha * MFC * density(diesel)
Kg/ha	=	(-) * (hr/ha) * (litres/hr) * kg/litre
Energyuse	=	Dieseluse * energy content diesel
MJ/ha	=	(kg/ha) * (MJ/kg)
Emissions	=	Energyuse * CO2dieselMJ
Kg CO2/ha	=	MJ/ha) * kg CO2/MJ diesel

4 Indirect energy use, fuels, emissions

The emissions are based on the idea that during every activity a fraction of the total weight of the tractor or other equipment is used. At the end of the lifespan, the machine is completely used, is totally "consumed". The used weight per operation of the machine is based on the used hours and the lifespan and is multiplied by the weight of the machine. The use of energy, lubricants and other materials and the related greenhouse gas emissions are expressed per kg of machine used. With every formula, the units are shown in the mine below, in italics.

AM	=	weight * (operation time / lifetime)
Kg/ha	=	*(kg) * ((hr/ha)/hr)*
AM	=	the used weight of a machine

The use of energy is calculated by the formula:

IndirMJ	=	[productionMJ
	+	(maint.tyres + maint.oil + maint.paper + repairs) * MaintMJ] * AM
MJ	=	[MJ/kg + (kg/kg +kg/kg + kg/kg + kg/kg) * MJ/kg] * kg

In which:

productionMJ	=	the MegaJoules for the production of a machine. Unit: MJ per kg of machine. The MJ are characterised by the type of energy carrier.
maint.tyres	=	replacement of tyres expressed per kg of machine over the total lifespan. The first set of tyres is included in the productionMJ. Unit: kg of tyre per kg of machine.
maint.oil	=	the use of oil and other lubricants. Unit: kg oil per kg machine
maint.paper	=	the use of paper, polypropylene, lead and other materials. Unit: kg materials per kg of machine
repairs	=	the fraction of the weight that is replaced during the lifespan of a machine. Unit: kg machine per kg of machine

The energy requirements are matched by different type of energy carriers.

Indelec	=	productionMJ * AM * 0.45
	+	(maint.tyres + maint.oil + maint.paper + repairs) * AM * MaintMJ * 0.22
MJ	=	*MJ * kg * (-) + (kg/kg) * kg * MJ * (-)*
Indgas	=	productionMJ * AM * 0.41
MJ	=	*MJ * kg * (-) + (kg/kg) * kg * MJ * (-)*
Indoil	=	productionMJ * AM * 0.07
	+	(maint.tyres + maint.oil + maint.paper + repairs) * AM * MaintMJ * 0.78
MJ	=	*MJ * kg * (-) + (kg/kg) * kg * MJ * (-)*
Indcoal	=	productionMJ * AM * 0.07
MJ	=	*MJ * kg * (-) + (kg/kg) * kg * MJ * (-)*

The values for energy use for production and maintenance are different for the different types of machines.

<u>Tractors:</u>

ProductionMJ: 12 MJ/kg, electricity (45 %), gas (41 %), fuel oil (7%) and coal (7%)
MaintMJ (maintenance & repair) 27.2 MJ/kg (electricity (22 %), heating oil (78 %)
Maintenance tyres: (Lifespan / 2500 – 1) * 0.098 (kg tyre / kg machine)
Maintenance oil: 0.097 * density(oil) * lifespan / kg tractor (kg oil / kg machine)
Maint. paper, polyprop. lead: (0.068 + 0.034 + 0.34) * avg speed * lifespan / kg tractor (kg material/kg machine)
Repairs: 0.20 (kg material / kg machine)
Avg-speed can be set at 7 km/h for tractors and harvesters.

<u>Combine harvesters:</u>

Production: 12 MJ/kg, electricity (45 %), gas (41 %), fuel oil (7%) and coal (7%)
Maintenance and repair: 27.2 MJ/kg (electricity (22 %), heating oil (78 %)
Maintenance tyres: (Lifespan / 2500 – 1) * 0.098 (kg tyre / kg machine)
Maintenance oil: 0.097 * density(oil) * lifespan / kg harvester
Maint. paper, polyprop., lead: (0.068 + 0.034 + 0.34) * avg speed * lifespan / kg tractor (kg material/kg machine)
Repairs: 0.32 (kg material / kg machine)

<u>Trailers</u>

Production: 10 MJ/kg, electricity (45 %), gas (41 %), fuel oil (7%) and coal (7%)
Maintenance and repair: 27.2 MJ/kg (electricity (22 %), heating oil (78 %)
Maintenance tyres: (Lifespan / 2500 – 1) * 0.098 (kg tyre / kg machine)
Repairs: 0.11 (kg material / kg machine)

<u>Machinery general</u>

Production: 10 MJ/kg, electricity (45 %), gas (41 %), fuel oil (7%) and coal (7%)
Maintenance and repair: 27.2 MJ/kg (electricity (22 %), heating oil (78 %)
Repairs: 0.34 (kg material / kg machine)

<u>Machinery tillage</u>

Production: 10 MJ/kg, electricity (45 %), gas (41 %), fuel oil (7%) and coal (7%)
Maintenance and repair: 27.2 MJ/kg (electricity (22 %), heating oil (78 %)
Repairs: 0.45 (kg material / kg machine)

Slurry tankers

Production:	10 MJ/kg, electricity (45 %), gas (41 %), fuel oil (7%) and coal (7%)
Maintenance and repair:	27.2 MJ/kg (electricity (22 %), heating oil (78 %)
Maintenance tyres:	(Lifespan / 2500 – 1) * 0.098 (kg tyre / kg machine)
Repairs:	0.21 (kg material / kg machine)

5 The scale of agricultural operations

The database developed and filled in the CFPAN project will contain data concerning direct and indirect energy use of machinery operations for different type of crops. Therefore it will be necessary to have a set of applied machine operations on the farm for all types of crops. A complete and detailed set of operations is only available under Dutch conditions. Cultivation of plants in the Netherlands is on a relatively small scale in comparison for example USA. However, a lot of ingredients of the feed in the Netherlands are from countries where plants are cultivated on large scale farms. In cultivation on a bigger scale a higher efficiency in energy use will be expected. Therefore a scale factor will be introduced to calculate the energy use of cultivated plants on a bigger scale. The base will be the calculated energy use machinery under Dutch conditions (i.e. a small scale).

Method

A spread sheet model of PPO is used to calculate the energy on a small and a big scale. Two different types of machine operations are analysed: soil cultivation (ploughing) and harvest (harvesting cereals), see Table 62. This two type of operations are applied in almost all plants and account for a major part of the energy use on a farm.

For a small scale is assumed plots of 5 hectare and a total amount of 100 hectare.
For a big scale is assumed plots of 20 hectare and a total amount of 400 hectare.
For ploughing and harvesting the following track and machinery data are used:

Table 62. Data used in the comparison of small scale and large scale cultivation operations.

	Soil cultivation small scale	Soil cultivation big scale	Harvest small scale	Harvest big scale
Track				
Power (kW)	4wd 70	4wd 140		
Weight (kg)	4,650	7,850		
Lifespan (yr)	12	12		
Intensity (hr/year)	600	600		
Machinery				
Type	plough (2 mouldboards)	plough (4 mouldboards)	combine harvester for cereals	combine harvester for cereals
Implement width (m)	1.20	2.40	4.60	9.20
Needed power (kW)	70	140	145	250
Weight (kg)	600	1,200	12,000	15,000
Lifespan (yr)	15	15	10	8
Intensity (hr/year)	160	160	200	300
Field efficiency (%)	80	90	80	90

Explanation:

- The track is used for multiple operations and therefore no over capacity is assumed.
- For ploughing on a bigger scale the same intensity is used. There will only be a minimum period of time. Therefore the farmer needs more ploughs instead of more time with one plough.
- For harvesting on a bigger scale a higher intensity is used. On a small scale frequently the harvester will not be used the whole period.
- For farming on a bigger scale there will be less loss of time because of the size of the plots.

Results

The following direct and indirect energy use are calculated for ploughing and harvesting(Table 63).

Table 63. Direct and indirect energy use for ploughing and harvesting in the case of small and big scale operations.

	Soil cultivation small scale	Soil cultivation big scale	Harvest small scale	Harvest big scale
Energy use				
Direct (MJ)	881	780	579	429
Indirect (MJ	279	234	641	348
Total (MJ)	1160	1014	1220	777

Of these result of energy use the following scale factors are calculated for the two different operations and two types of energy use(Table 64).

Table 64. The efficiency of large scale operations compared to small scale in the case of ploughing and harvesting.

	Soil cultivation small scale	Soil cultivation big scale	Harvest small scale	Harvest big scale
Factor				
Direct	1	0.89	1	0.74
Indirect	1	0.84	1	0.54
Total	1	0.87	1	0.64

The efficiency gains for direct and indirect energy on large scale farms are higher for harvesting than for ploughing. On large scale farms the harvester can be used more efficient as a result of using the harvester more hours a year. In comparison with ploughing the extra needed power is relatively smaller with a harvester.

We propose to use the average value for harvester and plough and for indirect and direct energy. The average scale factor for large scale farms is calculated as follows:

Total scale factor = (1014+777) / (1160+1220) = 0.75

Conclusions

There will be differences in scale factors for energy use between different machinery operations. Also the effects in direct and indirect use of energy will be different.
Although differences are found in both operations and both type of energy uses a significant efficiency is calculated. Also the differences in scale factors can be explained by the chosen assumptions.

Taken account of these calculations, by filling the database in the CFPAN project one scale factor will be used for all machinery operations and for direct and indirect use. Two classes will be used: small scale and big scale
For the scale factor will be used the weighted average of the above calculated factors.

Energy use big scale = Energy use small scale * 0.75.

Appendix 4 Calculation of manure application

From the literature search performed in this project, we conclude that little data is available concerning the application of animal manure. This parameter will thus have to be assessed on the basis of a computation method. This chapter describes the methodology with which nitrogen availability per hectare of land is computed.
This methodology consists of several steps. These steps are:

1. Generating data on N excretion by animals on a country basis
2. Generating data on the N losses per country, per animal type and per Manure Management System (MMS)
3. Computing the N availability per country per animal type per MMS
4. Totalizing the available manure N per country
5. Generating data on areas of arable land, permanent crops and grassland
6. Allocating the available N to the land area per country

Nitrogen excretion of animals
The IPCC defines the N excretion of animals in the Tier 1 approach as a nitrogen excretion per 1000 kg of live weight. The FAO studies on GHG emissions of the livestock sector (FAO, 2010 and unpublished) provide data about the average live weight of the different animal types per country (or per group of countries).
The total nitrogen excretion of the herd is based on the excretion per animal and the total number of animals. The numbers of animals per country can be found in FAOstat.
Nitrogen is lost during storage. The fraction of N losses depends on the storage type. The IPCC 2006 Guidelines provides data about the total N losses during storage. This only counts for the losses to the air. Losses by leaching are defined by Miterra (Velthof et al.., 2009). An elaboration of the Miterra data for other types of manure storage has been made for the FAO-GHG studies (Vellinga, personal communication).
The different types of manure storage can be based on the data from the National Inventory Reports that are made by all Appendix 1 countries. They can be matched with the figures on nitrogen losses of the IPCC Guidelines (2006). Additional information about manure storage in non-Appendix 1 countries is derived from FAO (2010) and related databases (Vellinga, pers. Comm.)

The partitioning of excreted nitrogen

Fraction of not utilised manure
Part of the manure, and with it, nitrogen is not returned to land by manure application. In many regions, manure is still considered as waste or a hazardous product that can't be transported and applied to agricultural land. This fraction varies per country and per region. Because detailed information is not available, we assumed no discharge of manure.

Manure utilisation to grassland or arable land
In practice, there is a relationship between the animal type and the way manure is partitioned to grassland or arable land.
Manure from ruminants (beef, dairy, sheep and goats) comes from systems that are partly grass based, especially beef cattle, sheep and goats are kept in more or less marginal grassland areas. The manure from grazing animals (dairy and beef cattle, sheep and goats) is returned to grasslands. The manure of housed beef cattle, sheep and goats is not expected to be applied on arable land. The largest fraction will return to grassland areas, the remainder is considered negligible. So nitrogen (and P and K) of beef cattle, sheep and goats is considered not to be applied on arable land.
Manure of housed dairy cattle can be applied to grassland, but also to the own fodder crops and to arable land. The land use statistics do not distinguish different classes for fodder crops and other arable crops.
Manure of industrialised systems of monogastrics as pigs and poultry are expected to be applied on arable land. Very often there is no relationship between the arable land for manure application and the land for feed production.
A number of crops do not receive animal manure, due to their cultivation pattern or susceptibility for an overload of specific nutrients. Because detailed information on manure application is lacking a simplified approach has been chosen. Per country, the area of arable land and the area of arable land, permanent crops and permanent meadows and pastures were generated from FAOSTAT. The area of

arable land was used to compute the upper limit of N availability per hectare per country. The area of arable land, permanent crops and permanent meadows and pastures was used to compute the lower limit of N availability per hectare per country. In Table 65, these upper and lower limits of N availability per hectare are provided. The average of the lower and upper limit is used as a default value, both limits are used to define the uncertainty range.

Manure quality
Modelling so far has been based on the N excretion of animals. We need a partitioning of manure in organic and mineral nitrogen. This partitioning is used in the allocation of applied manure to specific crops and to other crops in the rotation. Losses of N during storage will be much higher than losses of P and K as both elements are not present in volatile forms. Because Nitrogen is the source of nitrous oxide emissions, application rates of Phosphorus and Potassium from manure are not taken into account.

Table 65. Total upper and lower limit of N availability per country (kg/ha)

Country	Maximum	Minimum	Average
Argentina	20	5	12
Australia	2	0	1
Belgium	114	70	92
Brazil	66	15	41
Canada	12	8	10
China	64	14	39
France	35	22	29
Germany	73	51	62
Hungary	15	11	13
India	20	18	19
Indonesia	26	11	18
Malaysia	44	10	27
Netherlands	291	162	227
Pakistan	32	25	29
Philippines	43	19	31
Poland	28	22	25
Thailand	15	12	13
Turkey	10	6	8
Uganda	27	12	20
U.K.	59	20	39
Ukraine	10	8	9
USA	19	8	14

Appendix 5 Emissions from crop residues

Table 66. The formulas of the IPCC Guidelines (IPCC, 2006) and the use of these formulas for the crops in the CFPAN project

NamUK	Crop residue	DS	Slope	Sig2	Int	Sig2	N_AG	BGAG_Rat	N_BG
Barley	barley	89	0.980	0.080	0.590	0.410	7	22	14
Barley	barley	89	0.980	0.080	0.590	0.410	7	22	14
Oats	oats	89	0.910	0.050	0.890	0.080	7	25	8
Corn	maize	87	1.030	0.030	0.610	0.190	6	22	7
Rye	rye	88	1.090	0.500	0.880	0.500	5	22	11
Wheat	wheat	89	1.610	0.030	0.400	0.250	6	23	9
Wheat	wheat	89	1.610	0.030	0.400	0.250	6	23	9
Buckwheat	grains	88	1.090	0.020	0.880	0.060	6	22	9
Rice	rice	89	0.950	0.190	2.460	0.410	7	16	9
Sorghum	sorghum	89	0.880	0.130	1.330	0.270	7	22	6
Triticale	wheat	89	1.610	0.030	0.400	0.250	6	23	9
Millet	millet	90	1.430	0.180	0.140	3.080	7	22	9
Beans	beans	91	1.130	0.190	0.850	0.560	8	19	8
Peas	dry beans	90	0.360	1.000	0.680	0.470	10	19	10
Lupines	N fixing forages	90	0.300	0.500	0.000	0.000	27	40	22
Lucerne	Alfalfa	90	0.290	0.310	0.000	0.500	27	40	19
Lentils	beans	91	1.130	0.190	0.850	0.560	8	19	8
Potatoes	potato	22	0.100	0.690	1.060	0.700	19	20	14
Potatoes	potato	22	0.100	0.690	1.060	0.700	19	20	14
Fodder beets	root crops	94	1.070	0.190	1.540	0.410	16	20	14
Sugar beets	root crops	94	1.070	0.190	1.540	0.410	16	20	14
Rapeseed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Linseed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Oil palm	-	-	-	-	-	-	-	-	-
Soy beans	soy bean	91	0.930	0.310	1.350	0.490	8	19	8
Sunflower	grains	88	1.090	0.020	0.880	0.060	6	22	9
Cotton seed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Poppy seed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Peanuts	peanut	94	1.070	0.190	1.540	0.410	16	19	10
Safflower seed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Sesame seed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Canary seed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Hemp	grains	88	1.090	0.020	0.880	0.060	6	22	9
Poppy seed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Niger seed	grains	88	1.090	0.020	0.880	0.060	6	22	9
Maize	maize	87	1.030	0.030	0.610	0.190	6	22	7
Grass	perennial grasses	90	0.300	0.150	0.000	0.000	15	80	12
Fodder beets	root crops	94	1.070	0.190	1.540	0.410	16	20	14
Lucerne	root crops	94	1.070	0.190	1.540	0.410	16	20	14
Cassava	root crops	94	1.070	0.190	1.540	0.410	16	20	14

Appendix 6 Data questionnaires crop production

For each crop in each country the data questionnaire are listed in

Table **67** and Table 68 were searched for.

Table 67. Data questionnaire input cultivation

Product	Parameter	Value				Unit
		Mean	SD	Min	Max	
Plant material	amount					kg/ha
Fertilizer	P_2O_5					kg/ha
	K_2O					kg/ha
	Ammonium nitrate (including CAN)					kg N/ha
	Ammonium sulphate					kg N/ha
	Urea					kg N/ha
	Other N-fertilizer					kg N/ha
Lime	lime					kg $CaCO_3$/ha
Manure	manure					kg N/ha
	manure					m^3/ha
	density					kg/m^3
	<u>Type of manure</u>					
	liquid manure					%
	solid manure hens and broilers					%
	solid manure other animals					%
	blood meal					%
	feather meal					%
	<u>Type of manure application</u>					
	liquid manure spreading					%
	Liquid manure injection					%
	solid manure spreading					%
	other					%
Pesticides	active ingredients					kg/ha
Land use	soil organic matter content					kg/kg
	% peat					%
	% soil type other 1					%
	% soil type other 2					%
	years in cultivation					year

Table 68. Data questionnaire output cultivation

Product name	Parameter	Value				Unit
		Mean	SD	Min	Max	
name product 1	yield					kg/ha
	dry matter content					kg/kg
	N-content					kg/kg
	P-content					kg/kg
	C-content					kg/kg
	Gross energy content					MJ/kg
	price					valuta per unit
name product 2	yield					kg/ha
	dry matter content					kg/kg
	N-content					kg/kg
	P-content					kg/kg
	C-content					kg/kg
	Gross energy content					MJ/kg
	price					valuta per unit
name product 3	yield					kg/ha
	dry matter content					kg/kg
	N-content					kg/kg
	P-content					kg/kg
	C-content					kg/kg
	Gross energy content					MJ/kg
	price					valuta per unit
above ground crop residue	N					kg/ha
	C-content					kg/kg
	fraction removed					kg/kg
	price					valuta per unit
below ground crop residue	N					kg/ha
	C-content					kg/kg

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