DRAFT FOR PUBLIC REVIEW

Environmental performance of animal feeds supply chains

Guidelines for quantification

LIVESTOCK ENVIRONMENTAL ASSESSMENT AND PERFORMANCE PARTNERSHIP

DRAFT FOR PUBLIC REVIEW

Environmental performance of animal feeds supply chains

Guidelines for quantification

Table of Contents

FOREWORD

The methodology developed in these draft guidelines aims to introduce a harmonized international approach to the assessment of the environmental performance of animal feed supply chains in a manner that takes account of the specificity of the various production systems involved. It aims to increase understanding of animal feed supply chains and to help improve their environmental performance. The guidelines are a product of the Livestock Environmental Assessment and Performance (LEAP) Partnership, a multi-stakeholder initiative whose goal is to improve the environmental sustainability of the livestock sector through better metrics and data.

The livestock sector has expanded rapidly in recent decades and because of sustained demand, especially in developing countries, is expected to continue growing. Population growth, greater purchasing power and urbanization all have been strong drivers of the sector's growth. With increasing livestock production, the demand for feedstuffs will also grow, putting greater pressure on natural resources. This is of particular concern since the livestock sector is already a major user of natural resources such as land and water, currently consuming about 35 percent of total cropland and about 20 percent of water for feed production (Opio et al., 2012). Globally, feed-related emissions (including land-use change) from the livestock sector account for about 3.3 gigatonnes CO_2-eq, that is, about half of total emissions from livestock supply chains (Gerber *et al.*, 2013). The feed sector is aware of this and increasingly there is a growing interest in measuring and improving the environmental performance of feed supply chains.

In the development of these draft guidelines, the following objectives were regarded as key:

- to develop a harmonized, science-based approach resting on a consensus among the sector's stakeholders;
- to recommend a scientific but at the same time practical approach that builds on existing or developing methodologies;
- to promote an assessment approach that can be applied equally across a broad range of feed supply chains; and
- To identify the principal areas where ambiguity or differing views exist as to the right approach.

Over the coming months these guidelines will be submitted to public review.[1] The purpose will be to strengthen the advice provided and ensure it meets the needs of those seeking to improve performance through sound assessment practice. Nor is the present document intended to remain static. It will be updated and improved as the sector evolves and more stakeholders become involved in LEAP, and as new methodological frameworks and data become available. The development and inclusion of guidance on the evaluation of additional environmental impacts is also viewed as a critical next step.

Lalji Desai

LEAP Chair

February 2014

[1] The public review period starts on 15 March 2014 and ends on 31 July 2014.

ACKNOWLEDGEMENTS

These guidelines are a product of the Livestock Environmental Assessment and Performance (LEAP) Partnership. Three groups contributed to their formulation:

The Technical Advisory Group (TAG) on animal feeds carried out the background research and developed the core technical content of the guidelines. The members of the animal feeds TAG were: Theun Vellinga (TAG leader, Wagingenin University, Netherlands), Sophie Bertrand (Centre National Interprofessionnel de l'Economie Laitière, the International Dairy Federation), Nicolas Martin (European Feed Manufacturers' Federation, FEFAC), Hans Luttikholt (National Oilseed Processers Association (US) and EU Vegetable Oil and Protein meal Industry), Bruno Caputi (Sindicato Nacional da Indústria de Alimentação Animal, SINDIRAÇÕES, Brazil), Hayo van der Werf (French National Institute for Agricultural Research), Li Yue (Institute of Environment and Sustainable Development for Agriculture, Chinese Academy of Agricultural Sciences), Raghavendra Bhatta (National Institute of Animal Nutrition and Physiology, Bangalore), Salil Arora (American Feed Industry Association, AFIA), Bernard A. Lukuyu (International Livestock Research Institute, Kenya), Thumrongsakd Phonbumrung (Department of Livestock Development, Thailand), Paul Crosson (The Irish Agriculture and Food Development Authority, Teagasc), Heinz Meissner (South Africa), Anna Flysjo (Arla Foods, Denmark) and Hans Blonk (Blonk Consultants, the Netherlands).

The LEAP Secretariat coordinated and facilitated the work of the TAG, guided and contributed to content development and made sure of the coherence among the various guidelines. The LEAP secretariat, hosted at FAO, was composed of: Pierre Gerber (Coordinator), Alison Watson (Manager), Carolyn Opio (Technical officer), Félix Teillard (Technical officer) and Aimable Uwizeye (Technical officer). Laura Drauker (World Resource Institute), Christel Cederberg (SIK and Chalmers University of Technology, Gothenburg) and John Kazer (Carbon Trust, London) assisted the Secretariat in reviewing these guidelines.

The LEAP Steering Committee provided overall guidance for the activities of the Partnership and helped review and cleared the guidelines for public release. During development of the guidelines the LEAP Steering Committee was composed of:

Steering committee members:

- Douglas Brown (World Vision)
- Elsa Delcombel (Government of France)
- Lalji Desai (World Alliance of Mobile Indigenous Peoples and Chair 2013 to 2014)
- Jan Grenz (Government of Switzerland)
- Vincent Guyonnet (International Egg Commission)
- Dave Harrison (International Meat Secretariat)
- Hsin Huang (International Meat Secretariat)

- Giuseppe Luca Capodieci (The European Livestock And Meat Trading Union)
- Delanie Kellon (International Dairy Federation)
- Lionel Launois (Government of France)
- Pablo Manzano (International Union for Conservation of Nature)
- Nicolas Martin (European Feed Manufacturers’ Federation)
- Paul McKiernan (Government of Ireland)
- Paul Melville (Government of New Zealand)
- Frank Mitloehner (University of California Davis and Chair 2012 to 2013)
- Anne-Marie Neeteson-van Nieuwenhoven (International Poultry Council)
- Frank O’Mara (Irish Agriculture and Food Development Authority, Teagasc)
- Antonio Onorati (International Planning Committee for World Food Sovereignty)
- Lara Sanfrancesco (International Poultry Council)
- Fritz Schneider (Bern University)
- Rogier Schulte (Government of Ireland)
- Henning Steinfeld (Food and Agriculture Organization)
- Bryan Weech (World Wildlife Fund)
- Geert Westenbrink (Government of the Netherlands)
- Hans-Peter Zerfas (World Vision)

Observers:

- Rudolph De Jong (International Wool Textile Organization)
- Matthias Finkbeiner (International Organization of Standards)
- Michele Galatola (European Commission)
- Sonia Valdivia (United Nations Environment Programme)
- Elisabeth van Delden (International Wool Textile Organization)

LEAP is funded by its Members, with additional support from FAO and the Mitigation of Climate Change in Agriculture (MICCA) Programme.

Although not directly responsible for the preparation of these guidelines, the TAGs on poultry and small ruminants indirectly contributed to their development through continuous exchanges throughout the preparation phase.

Recommended citation: LEAP, 2014. Environmental performance of animal feeds supply chains: Guidelines for quantification. Livestock Environmental Assessment and Performance Partnership. FAO, Rome, Italy.

GLOSSARY

Acidification	Impact category that addresses impacts due to acidifying substances in the environment. Emissions of NOx, NH_3 and SOx lead to releases of hydrogen ions (H+) when the gases are mineralized. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low, resulting in forest decline and lake acidification.
Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.
Attributional	Refers to process-based modelling intended to provide a static representation of average conditions, excluding market-mediated effects.
Background processes	Stages of the supply chain which provide goods and services to the foreground system; not under the control of the study commissioner. See also: **Foreground process.**
Biogenic	Derived from biomass, but not from fossilized or fossil sources.
Biomass	Material of biological origin, excluding material embedded in geological formations or transformed to fossil.
Capital goods	Goods, such as machinery, equipment and buildings, used in the life cycle of products.
Carbon dioxide equivalent (CO_2 eq.)	Unit for comparing the radiative forcing of a GHG to carbon dioxide (ISO 14064-1:2006, 2.19) expressed in terms of the amount of carbon dioxide that would have an equivalent impact. The carbon dioxide equivalent value is calculated by multiplying the mass of a given GHG by its global warming potential (see also definition of global warming potential).
Carbon footprint	The level of greenhouse gas emissions produced by a particular activity or entity or product.
Carbon sequestration	Removal of carbon from the atmosphere.
Carbon storage	Retention of carbon of biogenic or fossil sources or of atmospheric origin in a form other than as an atmospheric gas.
Characterization	Calculation of the magnitude of the contribution of each classified input/output to their respective impact categories, and aggregation of contributions within each category. This requires a linear multiplication of the inventory data with characterization factors for each substance and impact category of concern. For example, with respect to the EF impact category "climate change", CO_2 is chosen as the reference substance and kg CO_2-equivalents as the reference unit.
Characterization factor	Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category indicator.
Classification	Assigning the material/energy inputs and outputs tabulated in Life Cycle Inventory to impact categories according to each substance's potential to contribute to each of the impact categories considered.
Combined heat and power (CHP)	Simultaneous generation in one process of usable thermal energy and of electrical and/or mechanical energy.

Comparison	A comparison of two or more products regarding the results of their life cycle assessment as according to these guidelines and not including a comparative assertion.
Consequential analysis	Analysis that identifies and models all processes in the background system. of a system in consequence of decisions made in the foreground system.
Consumable	Ancillary input that is necessary for a process to occur but that does not form a tangible part of the product or co-products arising from the process.
Co-production	A multifunctional process with the production of the various products cannot be independently varied, or only varied within a very narrow range.
Co-product	Output from a production activity that generates more than one output. The term does not include services that may also be provided.
Cradle-to-gate	Life-cycle stages from the extraction or acquisition of raw materials to the point at which the product leaves a defined output point or gate.
Critical review	Process intended to ensure consistency between a life cycle assessment and the principles and requirements of this guide.
Crop product	Product from a cultivation system that can either be used directly as feed or as raw material in food or feed processing.
Crop rotation	Growing of crops in a seasonal sequence to prevent diseases, maintain soil conditions and optimize yields.
Cultivation	Activities related to the propagation, growing and harvesting of plants including activities to create favourable conditions for their growing.
Data quality	Characteristics of data relating to their ability to satisfy stated requirements.
Delayed emissions	Emissions that are released over time, e.g. through prolonged use or final disposal stages, versus a single, one-time emission.
Direct energy	Energy used on-farm for feed production and processing activities (e.g. cultivation, processing of feed materials).
Downstream	Occurring along a product supply chain after the point of referral.
Economic value	Market value of a product, co-product or residual material at the point of production.
Ecotoxicity	Environmental impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Ecotoxicity is a result of a variety of different toxicological mechanisms caused by the release of substances that have a direct effect on the health of the ecosystem.
Emission factor	Amount of emissions to land, water or air, expressed as unit emission and relative to a unit of activity (e.g. kg CO_2 eq. per unit input). NOTE Emission factor data is obtained from secondary data sources.
Emission Model	Mathematical description, with parameters and emission factors that describe the relationship between the input and the emission to land, water or air.
Emissions	Release of substance to air and discharges to water and land.

Environmental impact — Any change to the environment, whether adverse or beneficial, that wholly or partially results from an organization's activities, products or services (EMAS regulation).

Eutrophication — Nutrients (mainly nitrogen and phosphorus) from sewage outfalls and (fertilized) farmland that accelerates the growth of algae and other vegetation in water. The degradation of organic material consumes oxygen resulting in oxygen deficiency and, in some cases, fish death. Eutrophication translates the quantity of substances emitted into a common measure expressed as the oxygen required for the degradation of dead biomass.

Evapotranspiration — Evaporation from the soil and soil surface where crops are grown, including the transpiration of water that actually passes through crops.

Extrapolated data — Refers to data from a given process that is used to represent a similar process for which data is not available, on the assumption that it is reasonably representative.

Feed — Any single or multiple materials, whether processed, semi-processed or raw, which are intended to be fed directly to food-producing animals. (Good practices for the feed industry, FAO and IFIF, 2010). In this guide, feed does not include feed additives.

Feed additive — Any intentionally added ingredient not normally consumed as feed by itself; whether or not it has nutritional value and which affects the characteristics of feed or animal products.

Foreground Process — The stages of the supply chain under the direct control of the LCA commissioner. For product developers and process operators, the foreground data is of special interest because direct changes in the system (by using other materials, designs, processes) have direct effects on the result, while background system impacts can be influenced only indirectly by the choices mentioned above. See also: **Background process**.

Global Warming Potential (GWP) — Capacity of a greenhouse gas to influence radiative forcing, expressed in terms of a reference substance (for example CO_2-equivalents units) and a specified time horizon (e.g. GWP 20, GWP 100, GWP 500 for 20, 100 and 500 years respectively). It is related to the capacity to influence changes in the global average surface-air temperature and subsequent changes in various climate parameters along with their effects, such as storm and intensity, rainfall intensity, frequency of flooding, etc.

Greenhouse gases (GHGs) — Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the earth's surface, the atmosphere, and clouds (PAS2050:2011, 3.24) GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluoro-carbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Human Toxicity – cancer — Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, penetration through the skin insofar as they are related to cancer.

Human Toxicity – non cancer	Impact category that accounts for the adverse health effects on human beings caused by the intake of toxic substances through inhalation of air, food/water ingestion, or by penetration through the skin insofar as such toxic substances are related to non-cancer effects not caused by particulate matter/respiratory inorganic or ionizing radiation.
Impact category	A class representing environmental issues of concern to which life cycle inventory analysis results may be assigned.
Impact category indicator	A quantifiable representation of the contribution of a product unit to the specific impact.
Ionizing radiation, human health	Impact category that accounts for the adverse health effects on human health caused by radioactive releases.
Input	Product, material or energy flow that enters a unit process.
Intermediate product	Output from a unit process that is an input to other unit processes that require further transformation within the system.
Joint production	A multifunctional process in which the production of the various products can be independently varied. For example, in a backyard system the number of poultry and swine can be chosen independently of one another.
Juvenile phase	An early phase of plant growth.
Land occupation	Impact category related to use (occupation) of land area by activities such as agriculture, roads, housing, mining, etc. Land occupation considers the effects of land use, the amount of area involved and the duration of its occupation (changes in quality multiplied by area and duration).
Land-Use Change (LUC)	Changes in the purpose for which land is used by humans (e.g. from forest to cropland or grassland, from forest land to industrial land).
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to end of life, inclusive of any recycling or recovery activity.
Life Cycle Assessment (LCA)	Compilation and evaluation of inputs, outputs and potential environmental impacts of a product system throughout its life cycle.
Life Cycle Impact Assessment (LCIA)	Phase of life cycle assessment that aims at understanding and evaluating the magnitude and significance of the potential environmental impacts for a system throughout the life cycle (International Organization for Standardization- ISO 14044:2006, 3.4). The LCIA methods used provide impact characterization factors for elementary flows to aggregate the impact to a limited number of midpoint and/or damage indicators.
Multi-functionality	If a process or facility provides more than one function, i.e. it delivers several goods and/or services ("co-products"), it is “multifunctional”. In these situations, all inputs and emissions linked to the process must be partitioned between the product of interest and the other co-products in a principled manner.

Normalization	After the characterization step, normalization is an optional step in which the impact assessment results are multiplied by normalization factors that represent the overall inventory of a reference unit (e.g. a whole country or an average citizen). Normalized impact assessment results express the relative shares of the impacts of the analyzed system in terms of the total contributions to each impact category per reference unit. When displaying the normalized EF impact assessment results of the different impact topics next to each other, it becomes evident which impact categories are affected most and least by the analyzed system. Normalized EF impact assessment results reflect only the contribution of the analyzed system to the total impact potential, not the severity/relevance of the respective total impact. Normalized results are dimensionless, but not additive.
Offsetting	Mechanism for claiming a reduction in GHG emissions associated with a process or product through the removal of, or preventing the release of, GHG emissions in a process unrelated to the life cycle of the product being assessed.
Output	A product, material or energy flow that leaves a unit process. Products and materials include raw materials, intermediate products, co-products and releases.
Ozone depletion	Impact category that accounts for the degradation of stratospheric ozone due to emissions of ozone-depleting substances, for example long-lived chlorine and bromine containing gases (e.g. CFCs, HCFCs, Halons).
Particulate matter/ respiratory inorganics	Impact category that accounts for the adverse health effects on human health caused by emissions of particulate matter (PM) and its precursors (NOx, SOx, NH_3).
Photochemical ozone formation	Impact category that accounts for the formation of ozone at the ground level of the troposphere caused by photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide (CO) in the presence of nitrogen oxides (NOx) and sunlight. High concentrations of ground-level tropospheric ozone damage vegetation, human respiratory tracts and manmade materials through reaction with organic materials.
Primary data	Directly measured or collected data representative of specific activities within the product's life cycle.
Product category	Group of products that can fulfil equivalent functions.
Product Category Rules (PCR)	Set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories.
Product Environmental Footprint Category Rules (PEFCR)	Product-type-specific, life-cycle-based rules that complement general methodological guidance for PEF studies by providing further specification at the level of a specific product category. PEFCRs can help to shift the focus of the PEF study towards those aspects and parameters that matter the most, and hence contribute to increased relevance, reproducibility and consistency.
Raw material	Primary or secondary material is used to produce a product. (Secondary material includes recycled material).
Reference flow	Quantity of a material, from a unit process in the supply chain which is required to produce the functional unit.
Releases	Emissions to air and discharges to water and soil.

Reporting	Presenting data to internal management and external users such as regulators, shareholders, the general public or specific stakeholder groups.
Residue	Material of which the upstream and production process that produce the output are not deliberately modified for the outputs. The material leaves the system in the condition as it appears in the process, but it has a subsequent use. Materials with economic value of higher than one percent of the turnover are not considered as a residue.
Resource depletion	Impact category that addresses the use of natural resources, renewable or non-renewable, biotic or abiotic.
Secondary data	Information obtained from sources other than direct measurement of the inputs/outputs (or purchases and emissions) deriving from processes included in the life cycle of the product (PAS 2050:2011, 3.41). *NOTE*: Secondary data are used when primary data are not available or when it is impractical to obtain primary data. Some emissions, such as methane from litter management, are calculated from a model, and are therefore considered secondary data.
Sensitivity analysis	Systematic procedures for estimating the effects of the choices made regarding methods and data on the results of an LCA study.
Soil Organic Matter (SOM)	The measure of the content of organic material in soil. This derives from plants and animals and comprises all the organic matter in the soil exclusive of the matter that has not decayed.
Subdivision	Subdivision refers to disaggregating multifunctional processes or facilities to isolate the input flows directly associated with each process or facility output. The process is examined to see whether it can be subdivided. Where subdivision is possible, inventory data should be collected only for those unit processes directly attributable to the products/services.
System boundary	Set of criteria specifying which unit processes are part of a product system (life cycle).
System expansion	Expanding the product system to include the additional functions related to the co-products.
Temporary carbon storage	Occurs when a product "reduces the GHGs in the atmosphere" or creates "negative emissions", by removing and storing carbon for a limited amount of time.
Uncertainty analysis	Procedure to assess the uncertainty introduced into the results of a PEF study due to data variability and choice-related uncertainty.
Unit process	Smallest element considered in the life-cycle inventory analysis for which input and output data are quantified.
Upstream emissions	Emissions associated with processes that occur in the life cycle of a product prior to the processes owned, operated or controlled by the organization undertaking the assessment.
Use phase	The part of the life cycle of a product that occurs between the transfer of the product to the consumer and the point of transfer to recycling and waste disposal (PAS 2050:2011, 3.46). The use phase of a feed corresponds to its consumption by animals on a farm and includes manure management.

Waste Waste is a substance or object produced by being an integral part of a process of production but where there is no subsequent use without any specific treatment and/or in accordance with regulations. See also Residue.

Weighting Weighting is an additional, but not mandatory, step that may support the interpretation and communication of the results of the analysis. The results are multiplied by a set of weighting factors, which reflect the perceived relative importance of the impact categories considered. Weighted EF results can be directly compared across impact categories, and also can be summed across impact categories to obtain a single-value overall impact indicator. Weighting requires making value judgments as to the respective importance of the impact categories considered. These judgments may be based on expert opinion, social science methods, cultural/political viewpoints, or economic considerations.

PART 1:

OVERVIEW AND GENERAL PRINCIPLES

1 INTENDED USERS AND OBJECTIVES

The methodology and guidance developed here can be used by stakeholders in all countries and across the entire range of animal feed production systems. In developing the guidelines, it was assumed that the primary users will be individuals or organizations with a good working knowledge of life cycle assessment. The main objective of the guidelines, in fact, is to provide a comprehensive definition of the calculation methods and data requirements needed to enable a consistent application of LCA across the diversity of feed supply chains.

This guidance is relevant to a wide array of livestock stakeholders including:

- Livestock producers who wish to develop inventories of their on-farm resources and assess the performance of their production systems.
- Supply chain partners such as feed producers, farmers and processors seeking a better understanding of the environmental performance of products in their production processes.
- Policy makers interested in developing accounting and reporting specifications for livestock supply chains.

The benefits of this approach include:

- Use of recognized, robust and transparent methodology developed to take account of the nature of feed supply chains;
- Identification of supply chain hotspots and opportunities to improve and reduce environmental impact;
- Identification of opportunities to increase efficiency and productivity;
- Ability to benchmark performance internally or against industry standards;
- Supporting reporting and communication requirements; and
- Raising awareness and supporting action on environmental sustainability.

2 SCOPE

2.1 Environmental impact categories addressed in the guidelines

These guidelines cover only the following environmental impact categories: namely, climate change, fossil energy demand, acidification, eutrophication, and land use. This document does not provide support for the assessment of comprehensive environmental performance nor to the social or economic aspects of feed supply chains.

The environmental impact categories were selected by the Technical Advisory Group (TAG) members, based on the following criteria:

- relevance for the feed and livestock sectors as well as to the agendas of governments, intergovernmental organizations, non-government organizations, civil society and the private sector;
- agreement in the LCA community on the validity of the impact categorization model (scientific consensus);
- quality and availability of characterization factors; and
- local versus global level of impact.

Biodiversity loss, water consumption, depletion of marine resources, soil degradation, and eco-toxicity are other environmental impacts that the TAG considered highly relevant but for which no universally accepted techniques are available. For this reason, they could not be included in the guidelines. Human toxicity, ozone depletion, ionising radiation and photochemical ozone formation were estimated to be less important impact categories.

In the guidelines, GHG emission from land-use-change is analysed and recorded separately from GHG emissions due to other sources. There are two reasons for doing this. The first is a question of time frame because emissions attributed to land-use-change may have occurred in the past or may be set to occur in the future. Secondly, there is much uncertainty and debate about the best method for calculating land-use-change.

Regarding land use, the areas under observation were divided into two categories: arable land and grassland. This indicator was included in the guidelines, as it provides important information about the use of a finite resource (land) but is also important when one considers the follow-on impacts on land degradation, biodiversity, carbon sequestration or loss, water depletion, and so forth. Nevertheless, users specifically interested in relating land use to follow-on impacts will need to collect and analyse additional information on production practices and local conditions.

2.2 Application

Some flexibility in methodology is desirable to accommodate the range of possible goals and special conditions arising in different sectors. This document strikes a pragmatic balance between flexibility and rigorous consistency across scale, geographic location, and project goals.

A more strict prescription on the methodology, including allocation and acceptable data sources, is required for product labelling or comparative performance claims. Users are referred to ISO 14025 for more information and guidance on comparative claims of environmental performance.

These guidelines are generally based on the attributional approach to life cycle accounting. The approach refers to process-based modelling, intended to provide a static representation of average conditions.

Due to the limited number of environmental impact categories covered here, results should be presented in conjunction with other environmental metrics to understand the wider environmental implications, either positive or negative. It should be noted that comparisons between final products should only be based on full life cycle assessment. Users of these guidelines shall not employ results to claim overall environmental superiority of to communicate overall environmental superiority of feed production systems and products.

The methodology and guidance developed in the LEAP Partnership is not intended to create barriers to trade or contradict any WTO requirements.

3 STRUCTURE AND CONVENTIONS

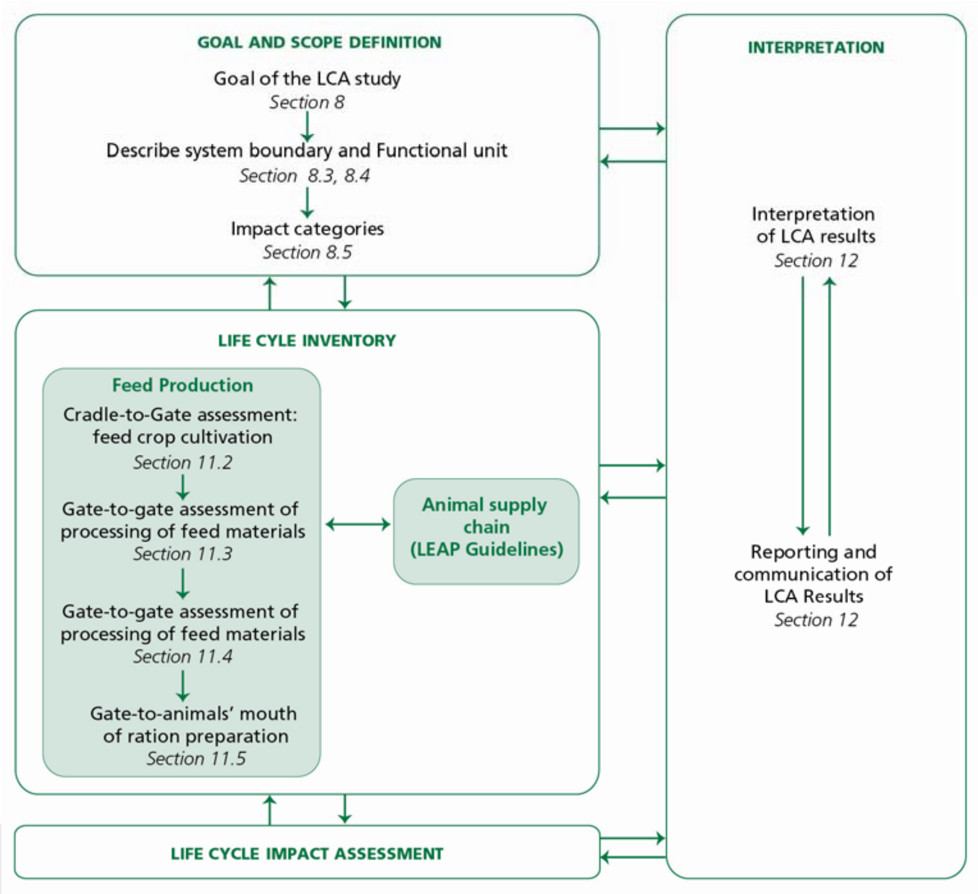
3.1 Structure

This document adopts the main structure of ISO 14040:2006 and the four main phases of Life Cycle Assessment – goal and scope definition, inventory analysis, impact assessment, and interpretation. Figure 1presents the general relationship between the phases of an LCA study defined by ISO 14040:2006 and the steps needed to complete a GHG inventory in conformance with this guidance. Part 2 of this methodology sets out the following:

- Section 7 outlines the operational areas to which these guidelines apply.
- Section 8 includes requirements and guidance to help users define the goals and scope, and system boundary of an LCA.
- Section 9 presents the principles for handling multiple co-products and includes requirements and guidance to help users select the most appropriate allocation method to address common processes in their product inventory.
- Section 10 presents requirements and guidance on the collection and assessment of the quality of inventory data as well as on identification, assessment, and reporting on inventory uncertainty.
- Section 11 outlines key requirements, steps, and procedures involved in quantifying GHG and other environmental impact inventory results in the studied supply chain.
- Section 12 provides guidance on interpretation and reporting of results and summarizes the various requirements and best practice in reporting.

A glossary intended to provide a common vocabulary for practitioners has been included. Additional information is presented in the appendices.

FIGURE 1: PRINCIPAL LIFE CYCLE STEPS IN THE ANIMAL FEED SUPPLY CHAIN



Users of this methodology should also refer to other relevant guidelines where necessary and indicated. The LEAP animal feed guidelines are not intended to stand alone but are meant to be used in conjunction with the LEAP Animal Guidelines. Relevant guidance developed under the LEAP Partnership but contained in other documents will be specifically cross-referenced to enable ease of use. For example, specific guidance for calculating associated emissions for feed of animal origin will be contained within the LEAP animal guidelines in order to facilitate measurement of the GHG emissions of the animal sectors.

3.2 Presentational Conventions

These guidelines are explicit in indicating which requirements, recommendations, or permissible or allowable options that users may choose to follow.

The term "shall" is used to indicate what is required for an assessment to conform to these guidelines.

The term "should" is used to indicate a recommendation, but not a requirement.

The term "may" is used to indicate an option that is permissible or allowable.

Commentary, explanations and general informative material (e.g. notes) are presented in footnotes, and do not constitute a normative element.

Examples illustrating specific areas of the guidelines are presented in boxes.

4 ESSENTIAL BACKGROUND INFORMATION AND PRINCIPLES

4.1 A brief introduction to LCA

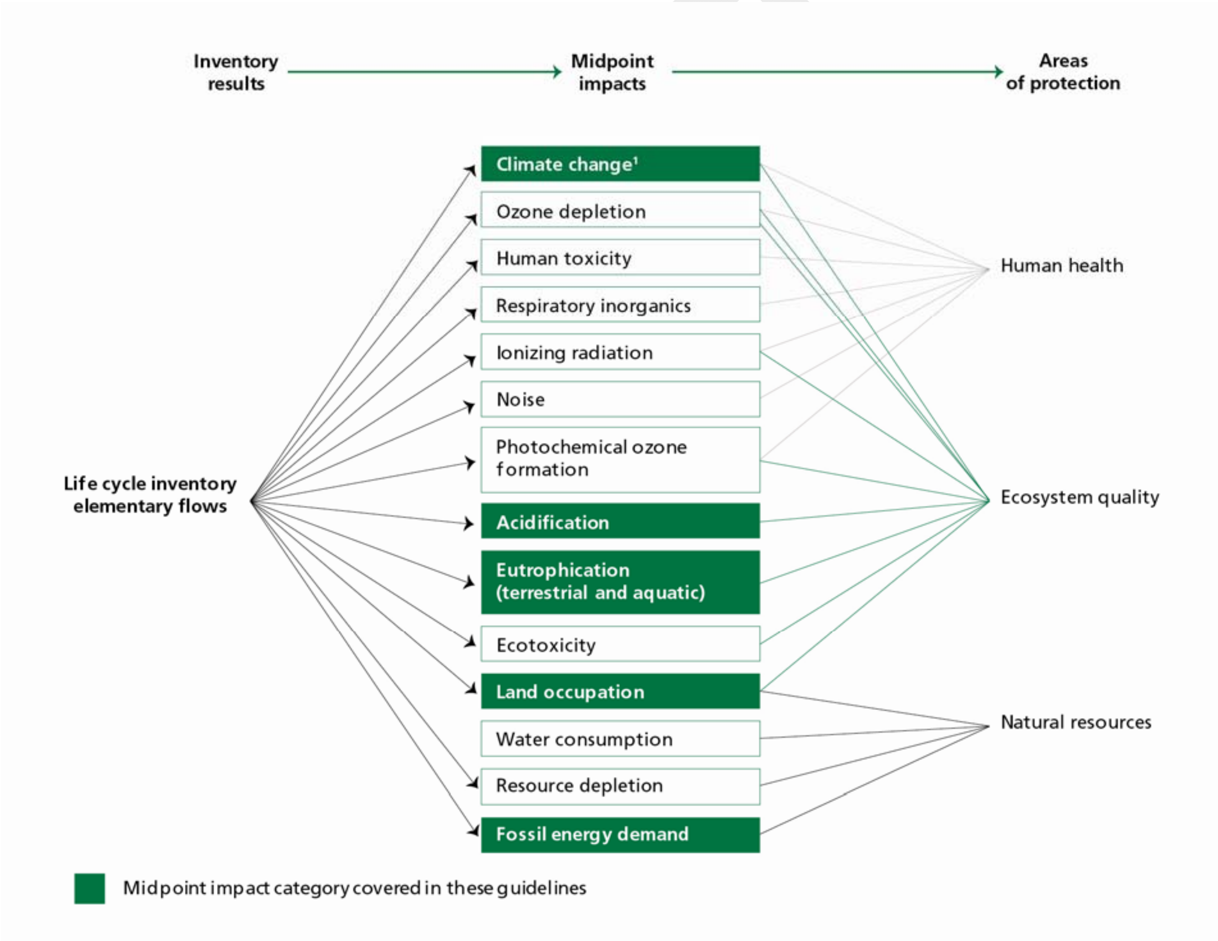
Life cycle assessment (LCA) is recognized as one of the most important methods developed to assess the environmental impact of products and processes. LCA can be used as a decision support tool within environmental management. ISO 14040:2006 defines LCA as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle". In other words, LCA provides quantitative, confirmable, and manageable process models to evaluate production processes, analyse options for innovation, and improve understanding of complex systems. LCA can identify processes and areas where process changes stemming from research and development can significantly contribute to reduce environmental impacts. According to ISO14040:2006, LCA consist of four phases:

- Goal and scope definition – including appropriate metrics (e.g. greenhouse gas emissions, water consumption, hazardous materials generated, and/or quantity of waste);
- Life cycle inventories (collection of data that identify the system inputs and outputs and discharges to the environment);
- Performance of impact assessment (application of characterization factors to the LCI emissions which normalizes groups of emissions to a common metric such as global warming potential reported in CO_2 equivalents);
- Analysis and interpretation of results.

4.2 Environmental impact categories

Life Cycle Impact Assessment (LCIA) aims at understanding and evaluating the magnitude and significance of potential environmental impacts for a product system throughout the life cycle of the product (ISO 14040:2006). The selection of environmental impacts is a mandatory step of LCIA and this selection shall be justified and consistent with the goal and scope of the study (ISO 14040:2006). Impacts can be modelled at different levels in the environmental cause-effect chain linking elementary flows of the life cycle inventory to midpoint and areas of protection (Figure 2).

FIGURE 2: ENVIRONMENTAL CAUSE-EFFECT CHAIN AND CATEGORIES OF IMPACT



[1:] In these guidelines, climate change impacts are reported separately for those related to GHG emissions along the feed supply chain and those related to land use change.

Source: adapted from ILCD, 2010.

A distinction must be made between midpoint impacts (which characterize impacts somewhere in the middle of the environmental cause-effect chain), and endpoint impacts (which characterize impacts at the end of the environmental cause-effect chain). Endpoint methods provide indicators at, or close to, an area of protection. Usually three areas of protection are recognized: human health, ecosystems, and natural resources. The aggregation at endpoint level and at the areas of protection level is an optional phase of the assessment according to ISO 14044:2006.

Climate change is an example of a midpoint impact category. The results of the Life Cycle Inventory are the amounts of greenhouse gas emissions per functional unit. Using a characterization model and a characterization factor such as the Global Warming Potential for each gas these results can be expressed under the same midpoint impact category indicator, i.e. kilograms of CO_2 equivalents per functional unit.

These guidelines provide guidance on a selection of midpoint impact categories and indicators (Figure 2). They do not, however, provide guidance or recommendations regarding endpoint methods.

4.3 Normative references

The following referenced documents are indispensable in the application of this methodology and guidance.

- ISO 14040:2006 *Environmental management – Life cycle assessment – Principles and framework*
  These standards give guidelines on the principles and conduct of LCA studies providing organizations with information on how to reduce the overall environmental impact of their products and services. ISO 14040:2006 define the generic steps which are usually taken when conducting an LCA and this document follows the first three of the four main phases in developing an LCA (Goal and scope, Inventory analysis, Impact assessment and Interpretation).
- ISO14044:2006 *Environmental management – Life cycle assessment – Requirements and guidelines*
  ISO 14044:2006 specifies requirements and provides guidelines for life cycle assessment including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.
- ISO 14025:2006 *Environmental labels and declarations – Type III environmental declarations – Principles and procedures*
  ISO 14025:2006 establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations. It specifically establishes the use of the ISO 14040 series of standards in the development of Type III environmental declaration programmes and Type III environmental declarations.

Type III environmental declarations are primarily intended for use in business-to-business communication, but their use in business-to-consumer communication is not precluded under certain conditions.

- ISO/TS 14067:2013 *Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication*
  ISO/TS 14067:2013 specifies principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product (CFP), based on ISO 14040 and ISO 14044 for quantification and on environmental labels and declarations (ISO 14020, ISO 14024 and ISO 14025) for communication.
- WRI/WBCSD (2011) *Product Life Cycle Accounting and Reporting Standard*
  The GHG Protocol from the World Resources Institute & World Business Council for Sustainable Development (WRI/WBCSD) provides a framework to assist users in estimating the total GHG emissions associated with the life cycle of a product. It is broadly similar in its approach to the ISO standards, although it lays more emphasis on analysis, tracking changes over time, reduction options and reporting. Like PAS2050, this standard excludes impacts from production of infrastructure, but whereas PAS2050 includes 'operation of premises' such as retail lighting or office heating, the GHG Protocol does not.
- British Standards Institution PAS 2050:2011 *Specification for the assessment of life cycle greenhouse gas emissions of goods and services*

  PAS 2050:2011(BSI 2011) is a Publicly Available (i.e. not standard) Specification. A UK initiative sponsored by the Carbon Trust and Defra, PAS 2050 was published through the British Standards Institution (BSI) and uses BSI methods for agreeing a Publicly Available Specification. It is targeted at applying LCA over a wide range of products in a consistent manner for industry users, focusing solely on the carbon footprint indicator. PAS 2050 has many elements in common with the ISO 14000 series methods but also a number of differences, some of which limit choices for analysts (e.g. exclusion of capital goods and setting materiality thresholds).

4.4 Guiding principles

Five guiding principles support users in their application of this sector-specific methodology. These principles are consistent across the methodologies developed within the LEAP Partnership. They apply to all the steps, from goal and scope definition, data collection and LCI modelling through to reporting. Adhering to these principles ensures that any assessment made in accordance with the methodology prescribed is carried out in a robust and transparent manner. The principles can also guide users when making choices not specified by the guidelines.

The principles are adapted from the WBCSD-WRI's Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard (2011), the BSI PAS 2050:2011, the ILCD Handbook and ISO/TS 14067:2013 and are intended to guide the accounting and reporting of environment impacts categories.

Accounting and reporting of GHG emissions and other environmental impacts from animal feed supply chains shall accordingly be based on the following principles:

Relevance

Data, accounting methodologies and reporting shall be appropriate to the decision-making needs of the intended users. Information should be reported in a way that is easily understandable to the intended users.

Completeness

All product life cycle GHG emissions, removals and sinks, and other environmental criteria within the specified – system and temporal – boundaries under study, shall be reported. Any specific exclusion shall be disclosed and justified.

Consistency

Consistent methodologies, data and assumptions shall be used throughout the assessment to allow for meaningful comparisons and reproducibility of the outcomes over time. Any changes to the data, boundaries, assumptions, methods, or any other relevant factors shall be reported and documented.

Accuracy

Bias and uncertainties shall be reduced as far as practicable. Sufficient accuracy shall be achieved to enable intended users to make decisions with reasonable confidence as to the reliability and integrity of the reported information.

Transparency

In external communications, sufficient information shall be disclosed and appropriate references made to allow third parties to verify all data, calculations and assumptions, and intended users to make associated decisions with confidence. A clear audit trail shall address all the relevant issues in a factual and coherent manner.

5 LEAP AND THE PREPARATION PROCESS

LEAP is a multi-stakeholder initiative launched in July 2012 with the goal of improving the environmental performance of livestock supply chains. Hosted by the Food and Agriculture Organization of the United Nations, LEAP brings together the private sector, governments, civil society representatives and leading experts who have a direct interest in the development of science-based, transparent and pragmatic guidance to measure and improve the environmental performance of livestock products.

Demand for livestock products is projected to grow 1.3 percent per annum until 2050, driven by global population growth and increasing wealth and urbanization (Alexandratos and Bruinsma, 2010). Against the background of climate change and increasing competition for natural resources, this projected growth places significant pressure on the livestock sector to perform in a more sustainable way. The identification and promotion of the contributions that the sector can make towards more efficient use of resource and better environmental outcomes is also important.

Currently, many different methods are used to assess the environmental impacts and performance of livestock products. This causes confusion and makes it difficult to compare results and set priorities for continuing improvement. With increasing demands in the marketplace for more sustainable products there is also the risk that debates about how sustainability is measured will distract people from the task of driving real improvement in environmental performance. And there is the danger that labelling or private standards based on poorly developed metrics could lead to erroneous claims and comparisons.

The LEAP Partnership addresses the urgent need for a coordinated approach to developing clear guidelines for environmental performance assessment based on international best practices. The scope of LEAP is not to propose new standards but to produce detailed guidelines that are specifically relevant to the livestock sector, and refine guidance as to existing standards. LEAP is a multi-stakeholder partnership bringing together the private sector, governments and civil society. These three groups have an equal say in deciding work plans and approving outputs from LEAP, thus ensuring that the guidelines produced are relevant to all stakeholders, widely accepted and supported by scientific evidence.

With this in mind, the first three technical advisory groups (TAGs) of LEAP were formed in early 2013 to develop guidelines for assessing the environmental performance of small ruminants (goats and sheep), animal feeds and poultry supply chains.

The work of LEAP is challenging but vitally important to the livestock sector. The diversity and complexity of livestock farming systems, products, stakeholders and environmental impacts can only be matched by the willingness of the sector's practitioners to work together to improve performance. LEAP provides the essential backbone of robust measurement methods to enable assessment, understanding and improvement in practice. More background information on the LEAP Partnership can be found at www.fao.org/partnerships/leap/en/

5.1 Development of sector-specific guidelines

Sector-specific guidelines to assessing the environmental performance of the livestock sector are a key aspect of the LEAP Partnership work programme. Such guidelines take into account the nature of the livestock supply chain under investigation and are developed by a team of experts with extensive experience in life-cycle assessment and livestock supply chains.

The benefit of a sector-specific approach is that it gives guidance on the application of life-cycle assessment to users and provides a common basis from which to evaluate resource use and environmental impacts.

Sector-specific guidelines may also be referred to as supplementary requirements, product rules, sector guidance, product category rules or product environmental footprint category rules – although each programme will prescribe specific rules to ensure conformity and avoid conflict with any existing parent standard.

The first set of sector-specific guidelines addresses small ruminants, poultry and animal feeds. The former two place emphasis on climate-related impacts, while the LEAP Animal Feed Guidelines address a broader range of environmental categories. LEAP is also considering developing guidance for the assessment of other animal commodities and wider environmental impacts such as biodiversity, water and nutrients.

5.2 The animal feeds TAG and the preparation process

The animal feeds TAG of the LEAP Partnership was formed at the start of 2013. It is made up of selected LCA and production system experts whose experience reflects complementarities among products, systems and regions, and whose backgrounds are varied enough to allow them to understand and address different interest groups with the necessary credibility.

The TAG's role is to:

- review existing methodologies and guidelines for the assessment of environmental impacts from livestock supply chains and to identify lacunae and priorities for further work;
- develop methodologies and sector-specific guidelines for the life cycle assessment of environmental impacts from feed supply chains; and
- provide guidance as to future work needed to improve the guidelines and encourage an even greater uptake of life-cycle assessment of environmental impacts from feed supply chains.

The TAG met for its first workshop from 12–14 February 2013. In July 2013, another workshop was organized to review the already existing draft feed guidelines developed by the European Feed Industry, FEFAC. The draft guidelines developed by the feed industry have served as a starting point for the development of LEAP animal feed guidelines. The review workshop drew a number of production systems experts from 11 countries including China, Kenya, India, Brazil, Colombia, Indonesia, Thailand, Malaysia, Japan, New Zealand, and Australia. A second face-to-face workshop of TAG members was organized from 5−7 September 2013 in Rome, Italy. Subsequently, the TAG continued to work via electronic communication (e-mails and teleconferences) until the completion of the first draft.

The animal feed TAG is composed of 15 experts representing a variety of professional backgrounds, all with extensive expertise in animal and feed supply chains including f leading LCA researchers and experienced industry practitioners. The TAG was chaired by Dr Theun Vellinga from Wageningen University, The Netherlands.

As a first step, existing studies and associated methods were reviewed by the TAG to assess whether they offered a suitable framework or approach for a sector-specific approach. This was done to avoidthe unnecessary confusion and duplication of work that might be caused by the development of potentially competing standards or approaches. It also follows established procedures as set by the broad international guidance systems as listed in Section 4.3, *Normative references.*

Several studies were identified by the TAG as addressing important aspects of feed supply chains. A review of these studies can be found in Appendix 1. As a result, it was determined that no existing approach or study set out a full comprehensive methodology for quantifying environmental performance across the supply chain and consequently that further work would be needed by the TAG to reach consensus on more detailed guidance.

5.3 Period of validity

It is intended that these guidelines will be periodically reviewed to ensure the validity of the information and methodologies on which they rely. At the time of development, no mechanism is in place to ensure such review. The user is invited to visit the LEAP website (www.fao.org/partnerships/leap) to obtain the latest version.

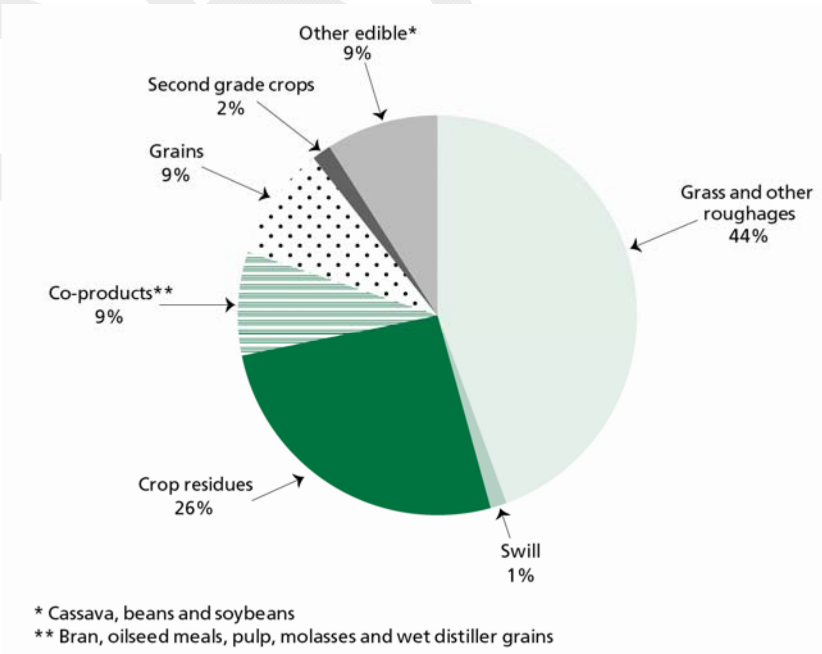
6 BACKGROUND INFORMATION ON FEED SUPPLY CHAINS

6.1 Background and context

The feed industry is a complex and very dynamic part of the agricultural industry. The last few years have been witness to rapid dietary changes with an increase, worldwide, in the demand for animal protein, including meat, dairy products and eggs. One consequence of this demand-led dietary transition in the human diet has been an increase in the demand for animal feed. At the same time, the feed sector faces a variety of challenges, arising from a dynamic, ever-changing environment, (including climate change and greenhouse gas emissions), increasing demand and competition for resources, as well as high, and volatile, commodity prices. Feed is usually the major cost or major resource associated with livestock production.

The animal feed sector depends on a number of sources for feed material including the crop production sector, the food industry, products deriving from the slaughter and processing of livestock, the marine industry, and biofuels. Consequently, feed supply chains vary greatly depending on the specific raw material and its intended uses. Broadly, a distinction can be made between ruminant and monogastric species; with the latter being largely dependent on feed materials from crop production such as grains, oil crops, and household waste, and the former on roughages such as grass, leaves and forage feedstuffs. Globally, livestock consumed 6.3 billion tonnes of feed (in dry matter) in 2005 (Gerber *et al.*, 2013), with ruminants consuming the bulk of feed (4.9 billion tons compared with 1.4 billion tons by pigs and poultry). Overall, grasses and roughages comprise about 44 percent of the feed used by livestock, followed by crop residues (28 percent). Grains, by-products from processing and other edible crops each comprised 9 percent of the feed used by the livestock sector while swill and second-grade crops comprised 2 percent and 1 percent, respectively (Figure 3).

FIGURE 3: FEED UTILIZATION BY THE LIVESTOCK SECTOR, 2005



Source: FAO Global Livestock Environmental Assessment Model (GLEAM), 2013.

Different feedstuffs are used for the production of different livestock commodities. Most feed grain (69 percent) is fed to pigs and poultry; the rest is used in ruminant production, particularly in dairy and beef production. Fibrous feeds (grass, leaves, fodder and crop residues) are of key importance in the diets of ruminants, which consume as much as 99 percent of fibrous feeds; the remainder is used in backyard pig production. This is in part determined by the physiological features of the two species; ruminants, in particular, have evolved with micro-organisms in the rumen capable of digesting fibrous feedstuffs. However, the inclusion of grain in ruminant diets, as a highly concentrated source of energy, can greatly enhance the efficiency of animal production.

The structure of animal feed supply chains is diverse, ranging from simple production units producing their own feed, or depending predominately on communal feed resources, to more complex feed production units where a variety of producers and industries contribute to the production, mixing, and distribution of feed ingredients and complete feed products. Part Two of these guidelines provides an overview of the diversity of feed chains (Section 7). In addition to being shaped by the feed demands of the different animal species, the feed supply chain is closely linked to the livestock production system. Feed use differs considerably among livestock production systems: Industrial pig and chicken systems primarily use grains, and other by-products from processing whereas mixed livestock systems − those where the majority of ruminant livestock (73 percent) are located largely use 69 percent of fibrous feeds (Gerber *et al.*, 2013).

As large-scale, concentrated livestock production methods have become the predominant model, animal feeds have been modified to include ingredients ranging from crop products and co-products from the processing and food industry, to rendered animals, antibiotics and additives. As livestock production becomes more intense, feed tends to be supplied more uniformly throughout the year with its nutritive requirements increasingly becoming a high priority. This is the case, for example, in large-scale industrial livestock operations such as poultry and pig production where individual farmers contract with vertically integrated corporations. Crop production and specialised feed processing plants thus have emerged, the idea being to ensure a steady supply of high quality and stable feed to these large-scale livestock production units.

In the more extensive grazing livestock systems, feeding systems are predominately land-based with animals grazed on natural or cultivated pastures, crop residues and forages or, in the case of pigs and poultry, raised in “backyard” systems. In such systems, animals to a large extent are reliant on local feed resources and there are no, or only limited inputs, in the production of feed. Feed materials may comprise of natural pastures, shrubs, crop residues, household waste, feed from forested areas, and so forth. However, a limited amount of supplementary feeding, e.g. use of oilseed meals or brans, crop residues, or concentrate feed, may occur during periods of scarcity.

6.2 Overview of environmental impacts from feed supply chains

Feed production is very important for all or a large fraction of the emissions of greenhouse gases in the life cycle of livestock supply chains. Beside the contribution to climate change, the feed supply chain contributes to other impacts such as eutrophication, acidification and fossil energy demand. Globally, GHG emissions from the production, processing and transport of feed account for about 45 percent of sector emissions.

At a species level, feed production for pork and chicken supply chains contributes 47 percent and 57 percent of emissions,, respectively (MacLeod *et al*., 2013). On the other hand, it constitutes 36 percent, 36 percent and 28 percent, respectively, of the total emissions for cattle, small ruminants and buffalo (Opio *et al*., 2013). Feed makes up a relatively smaller proportion for ruminants; methane from feed digestion is, after all, a large contributor to ruminant systems and hence comprises the dominant fraction of total emissions.

Fossil carbon dioxide (CO_2) and nitrous oxide (N_2O) are the dominant greenhouse gases emitted in animal feed production. The fertilization of feed crops and the deposition of manure on pastures generate substantial amounts of N_2O emissions, together representing about half of feed emissions (i.e. one-quarter of the sector's overall emissions). CO_2 derives largely from the use of fossil fuels, particularly diesel in tractors and harvesting machinery, oil in dryers and natural gas in the manufacture of mineral fertiliser nitrogen. In the post-farm stages, CO_2 is emitted in conjunction with various feed processes and is associated with processing, mixing, and distribution of feed ingredients.

Among feed materials, grass and other fresh roughages account for about half of the emissions, mostly from manure deposition on pasture and from direct land-use change. Crops produced for feed account for an additional quarter of emissions, and all other feed materials (crop by-products, crop residues, fishmeal and supplements) for the remaining quarter (Gerber *et al*., 2013).

Feed is what links livestock to land use, both directly via grazing and indirectly via traded feedstuffs. Global changes in the way land is managed and the appropriation of natural habitats such as forest land have been partly driven by the need to provide feed for animal protein production. Global croplands for feed and pasture areas have expanded in recent decades, accompanied by large increases in inputs such as energy, water, and fertilizer consumption resulting in considerable losses of biodiversity. In addition, land use and land-use change (LULUC) account for a large amount of greenhouse gas emissions in animal feed production.

About one-quarter of feed supply chain related emissions (about 9 percent of the livestock sector's emissions) are related to land-use change (Gerber *et al.*, 2013). Land-use change may be followed by distinct or drastic changes in land quality, such as decreases in biodiversity, increased soil compaction, loss of nutrients, impacts on water availability and quality, etc. These quality losses constitute the ecological damage from land-use change.

Land use for animal feed production can also be positive for the carbon balance as the soil acts as a carbon sink as opposed to being a source of emissions e.g. with deforestation as a consequence. Permanent, well-managed grassland is a form of land use that has the highest potential to function as a carbon sink. In addition to the impacts from GHG emissions, land use can have wider environmental impacts on soil, water, microclimate, and vegetation.

PART 2:

METHODOLOGY FOR QUANTIFICATION OF ENVIRONMENTAL IMPACTS FROM FEED PRODUCTS

7 DEFINITION OF THE PRODUCT GROUP

7.1 Product description

Feed is considered an intermediate product in the life cycle of livestock supply chains and therefore it is difficult to define it by its function in respect to human consumption. The approach adopted in this guidance is to define feed by its nature, i.e., as any single, or multiple, material, whether raw, semi-processed, or processed, that is intended to be fed directly to livestock. Feed additives such as minerals, synthetic amino acids etc. are considered as feed in these guidelines; however, detailed guidance regarding the production of feed additives will not be provided. The only guidance provided will be that on data sources for secondary data.

These guidelines cover all materials from plant or animal origins that are used by animals as feed. The main feed categories covered under these guidelines include:

- forage plants
- plant products and co-products
- feed of animal origin
- surplus food from households and food industry

A more detailed and comprehensive classification of feed is found on the website, www.feedipedia.org.

In many feed production chains additives make a significant contribution to feed rations and shall therefore be taken into account. However, the current guidelines refer only to the production of feed and not that of additives. Guidelines for feed additives are highly relevant, but are very complex and are still under development. The present guidelines will provide guidance on where to find secondary information on feed additives, so that they can be incorporated in the calculation of animal rations.

7.2 Life cycle stages: modularity

This guidance has been formulated to assess all feed supply chains, from the simplest situations, e.g. animals browsing in a pasture, to the most complex chains involving multiple products, processing and transportation. In all cases, the guidelines cover the feed chain from the production of raw materials to the time feed is ingested by animals, i.e. "*from cradle-to-the-animal's mouth*".

There is a wide range of feed chain types. Although not necessarily present in every supply chain, typical stages include *feed production*, *processing*, *feed compounding* and *feed preparation at the farm*, with *transport and trade* activities linking these different stages (Box 1).

To deal with the large variety of feed supply chains and to preserve maximum flexibility, this guidance and methodology will be based a modular approach (Figure 4). This will allow the user to utilize only those modules that are relevant to the supply chain s/he is analysing.

Box 1: Stages in feed supply chains

A feed supply chain can be divided into four main stages:

Feed production stage. Most feed products are of plant origin with their production starting with crop cultivation. Feed crop cultivation takes place in a wide range of cropping systems with varying practices including intercropping, perennial cropping systems, grazing systems and silvo-pastoral systems. Important non-plant sources of raw materials for feed include animal co-products such as dairy products, animal fats and oils, blood, and fishmeal and oil.

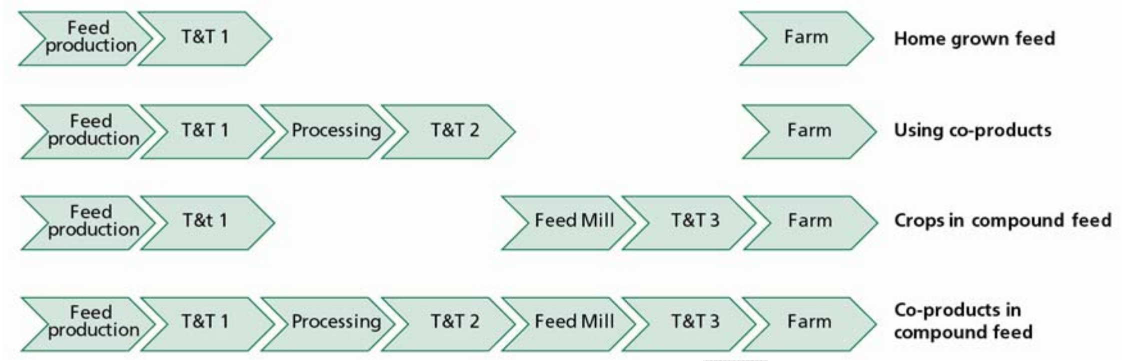
Processing stage. Processing of feed can range from simple on-farm processing of crop residues using chaffer cutters or feed pulverizers with low energy inputs to more complex, specialized industrial processes producing more than one co-product, such as the wet milling process for maize.

Feed mill stage. This stage includes both animal feed compounding and comprises the blending of various feedstuffs and additives.

Farm. The on-farm feed stage includes all those activities associated with preparing the feed for the animal. In some situations, feed is fed to animals without any further processing or mixing while in other circumstances farmers prepare rations by blending all feedstuffs into a single, complete ration.

Transport and storage can be considered an intermediate step linking the four main stages and will differ depending on the feed chain type. Transport utilization across the feed supply change can range from nil (e.g. in grazing feeding systems) to the use of animal draught power (e.g. in mixed livestock-cropping systems) or reliance on internationally-traded feed materials. *Storage* in the intermediate step is used only when this is related to transport and trade. In situations where storage of the product is the responsibility of the owner of one of the four stages, it is incorporated into that particular stage.

FIGURE 4: MODULAR SCHEME OF FEED PRODUCTION CHAINS



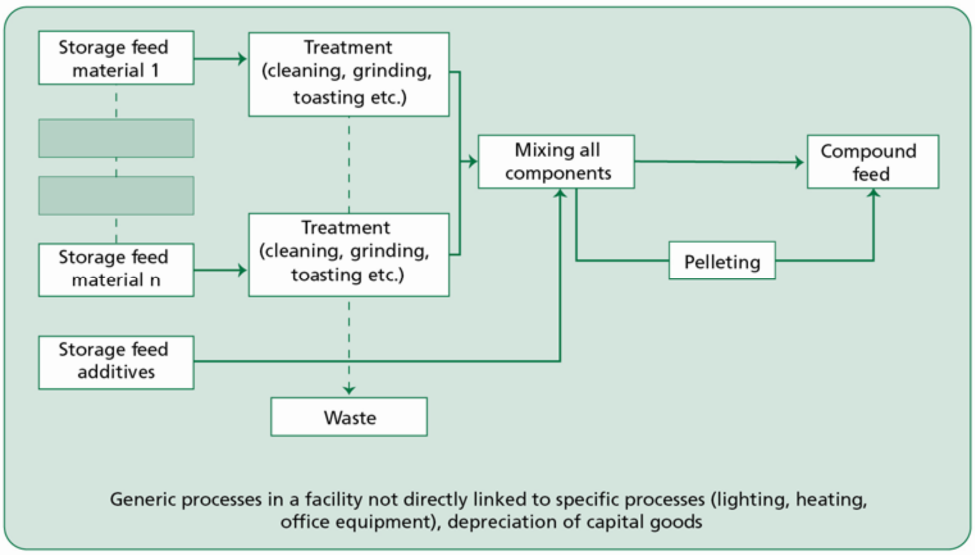
The final destination stage for every feed is the farm. The first stage (feed production) depends on the feed type: for plant-based feed the first stage corresponds to cultivation while animal-based feed enters the chain at the processing stage, and feed additives enter the chain mainly at the compound feed stage. Variations within the feed chain are, however, possible and the current modular approach captures these (Box 2). For example, additives sometimes can enter the feed chain at the processing stage or, alternatively, only at the farm stage. The transport and trade (T&T) link between the stages may be applied where relevant. However in situations where transport does not occur or is very limited, this can be omitted from the analysis. This is very often the case in extensive grazing systems where no transport occurs, or for home-grown feedstuffs, where transport takes place as part of the harvesting activities. Four examples of feed chains are shown in Figure 4.

- *Home-grown feed* represents a production chain where the feed produced is immediately utilized by the animal, and may or may not include on-farm storage before utilization. In this type of feed chain, there are a variety of examples ranging from very basic systems, such as grazing of natural pastures or crop residues, to cut-and-carry systems producing either fresh or conserved fodder or, in yet another option, to grains directly fed to animals. Such types of feed chains are generally short cycles with production often taking place very near the point of livestock rearing (Box 3).
- *Using co-products from processing industry* includes an additional stage, the processing of the raw material as well as storage and transport of the raw material from the field-gate to the processing unit and then to the farm. Some feed materials may undergo only minimal processing such as roasting/toasting of feed grain with no resulting co-products. Additionally, crop and animal products can be processed into several co-products that are used for food, feed and, in some cases, in other non-food sectors, for example vegetable oil extraction from oilcrops. In other situations, residues from industrial processes such as sugar production,

biofuel production, vegetable and fruit processing may be used as feed after further processing.

- *Primary crops used in compound feed* includes a feed mill stage where feedstuffs are blended into a compound feed from various raw materials and additives. Compound feed may be in the form of mixed meals or pellets and the ingredients used in animal feed can include cereals, cereal by-products, proteins (from either vegetable or animals sources), co-products from human food manufacture, minerals, vitamins and feed additives (Figure 5).

FIGURE 5: PRODUCTION PROCESS OF COMPOUND FEED

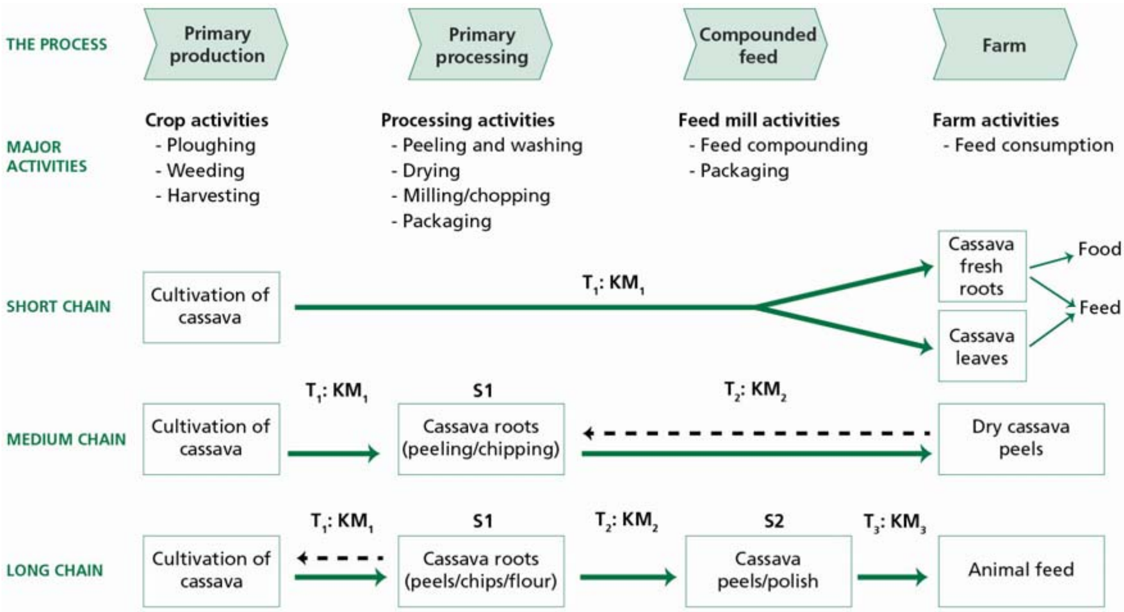


- *Co-products from processing compound feed* combines the above three stages and is an example of a long and complex feed chain.

BOX 2: CASSAVA-BASED FEED VALUE CHAINS IN WEST AFRICA

Figure 6 illustrates that within one crop a variety of feed chains can be distinguished and that the modular approach described here can deal with this kind of complexity. In this example, 3 types are feed chains are described: *short, medium and long*.

FIGURE 6: CASSAVA-BASED VALUE CHAIN CASE-STUDY FROM WEST AFRICA



Short chain: Cassava is produced mainly on-farm for household consumption. In this situation, the cassava leaves may be collected and or dried under the sun for livestock feed. In other cases, the cassava is peeled for food (fresh or chipped for flour) while cassava peels are dried for livestock feed. In this example, there is hardly any need for storage and Transport (T_1) is usually manual and distance from the field to the homestead (KM_1) ranges between 200 and 500m.

Medium chain: Cassava is produced on-farm and delivered to a farmers' organization for primary processing (peeling, chipping and drying). The chips are sold in local markets for food while cassava peels are dried for livestock feed and sold to farmers. Transport ($T_{1,\ 2}$) from farms to collection points (is often by tricycles or trucks) with a distance ($KM_{1,\ 2}$) of approximately 1 to 5 kms.

Long chain is commonly referred to as the Garri plant cassava supply chain. The Garri plant contracts farmers to produce cassava and organizes transport to collect cassava from farmers. The cassava is processed at the plant; cleaned, peeled, chipped and milled into flour for food. The Cassava peelings are currently disposed of as manure (efforts to convert them into feed are underway). The cassava polish, however, is packed and used in compounding poultry feeds. Although the environmental impact of cassava cultivation can be similar in all situations, the impact of the feed at farm level may differ significantly due to the variations in the supply chain.

Box 3: Examples of pastoralist feed chains

A Masaai Family in Tanzania: In this example, the Masaai household owns 300 head of cattle, 50 sheep, 60 goats, 7 donkeys, 20 chickens and 5 dogs. The land is not individually owned; the family uses communal pastures. Cattle, small ruminants and donkeys are predominantly fed on natural grasslands. Animals graze in one area for about six months during the rainy season. During the dry season, the household searches for other grazing land to where they can move the animals. This mobile system of seasonal and cyclical migration has been practised for decades. The family uses no input on grass production: however, during very dry years, when there is a shortage of grass, the animal ration is supplemented with crop residues obtained from local crop farmers. In this system, there are no inputs that go towards grass production on the farm. Milk is produced only during the rainy season and any surplus is sold. In the dry season the milk yield is very low. Animals are generally used for own consumption: they are slaughtered and consumed during ceremonies, offered as a dowry, and sold only when there is a need for cash.

The Sahel: Pastoralists in the Sahel generally have no formal land ownership, graze their animals on communal land, and use no external inputs to manage grasslands. An extended family (of about 30 people) in the north of the Sahel region keep 200 head of cattle, more than 300 sheep and 400 goats, 50 camels, 30 donkeys, 5 horses and 10 dogs. In normal years, the animals are grazed on the communal pastures, moving to better pastures during the dry season. During the last couple of decades, dry spells have become a frequent phenomenon, occurring on average once every 3 years. As a result pastoralists have been forced to develop coping strategies. Farmers in the south of the Sahel also face very harsh climatic conditions, with only 4 months of feed availability. The reminder of the year is spent travelling in search of additional feed resources such as grass and crop residues. Close to rivers the availability of crop residues and concentrates is higher than in remote regions.

In anticipation of feed scarcity, farmers begin by selling off the most vulnerable species in the herds of cattle and sheep. In addition, they make advance purchases of crop residues of millet, sorghum and cowpea from other farmers. Farmers also supplement their feed stores by purchasing oilseed cakes (e.g. sunflower, cottonseed) and wheat bran. Crop residues usually are not transported; herders have to move their herds to pastures located next to sedentary farmers. Aside from the precautionary sales mentioned above, generally few animals are sold. The majority is used for home consumption (either for regular meals or at ceremonies) or given away to the poor. Animals are usually sold only when the household is in need of cash.

8 GOAL AND SCOPE DEFINITION

8.1 Goal of the LCA study

The first step required when initiating an LCA is to set the goal or statement of purpose clearly. This describes the goal pursued and the intended use of results. There are numerous reasons for performing an LCA. An LCA can be used for emission management by determining the environmental footprint of products, localizing emission hotspots and prioritizing emissions-reduction opportunities along supply chains. LCAs provide detailed information on a product's environmental performance and can be used to meet performance tracking goals as well as to set progress and improvement targets. They could also be utilized to support reporting on the environmental impacts of products, although it should be noted that the current guidelines are not intended for product comparison or environmental performance labelling.

It is of paramount importance that the LCA's objectives be precisely identified because these early decisions define the overall design of the study. Only if goals are clearly articulated can it be ensured that aims, methods and results are aligned. For example, detailed quantitative studies, based on extensive data collection, will be required for benchmarking or for reporting at production-unit level. But greater level of generalization and simplification may be acceptable for hotspot analysis at sector or supply chain levels.

Seven aspects shall be addressed and documented during the process of goal definition:

- The subject of the analysis including the key properties of the assessed system such as organization, location(s), dimensions, products, sector and position in the value chain;
- the purpose for performing the study and context;
- intended use of the results: will the results be used internally for decision-making purposes or shared externally with third parties;
- target audiences;
- limitations of the methodology, assumptions, and impact coverage: in particular, the limitations associated with limited-impact categories should be addressed;
- comparative studies to be disclosed to the public and the need for critical review; and
- the study commissioner and other relevant stakeholders.

8.2 Scope of the LCA

The scope is defined in the first stage of an LCA, as an iterative process along with that of goal definition. It states the depth and breadth of the study. The scope shall identify the product system or the process to be studied, the functions of the system, the functional unit, the system boundaries, the allocation principles, and the impact categories. The scope should be defined so that the breadth, depth and detail of the study are compatible and sufficient to achieve the stated goal. While conducting an LCA of livestock or feed products, the scope of the study may need to be modified as information is collected to reflect data availability. Specific guidance is provided in the following sections.

8.3 Reference flows

The reference unit at all stages of the feed supply chain, including the intermediate stage, is a weight quantity with a predefined list of characteristics (see Appendix 2 on feed characteristics).

The following characteristics are recommended as minimum requirements:

- dry matter content of the material (kg/kg); and
- gross energy of the material (MJ/kg, based on low heating value).

An extended list is available in the Appendix on feed characteristics
The feed characteristics preferably shall be based on primary data. In the event primary data is unavailable, data should be used from accepted national or regional standardized databases. An example is the list in the "Nutrient requirements of dairy cattle (NRC, 2001; 7th Ed., Nat. Acad. Press, Washington, DC).

But this is not always easy. For example, where feed is immediately ingested by a grazing animal, yields are often not known while, in contrast, the yields of additional feed intake from other roughages or concentrates are available. In the examples regarding pastoralists in Africa (Box 3), even other feed intake is rarely known.

In such cases, the amount of feed consumed by animals is best estimated indirectly according to the energy requirements listed in the LEAP Poultry and Small Ruminants Guidelines. It should also be possible to use other simple indicative reference units such as a livestock unit or a one-animal-grazing-day per production cycle.

The production cycle is essential for multiple harvests per year as, for example, two to three cuts of alfalfa or grass. But it is also important for multiple cropping systems where two or three complete production cycles of sowing and harvesting are completed per annum. Hence, the length of the production cycle is not automatically one year.

8.4 System boundary

8.4.1 General / Scoping analysis

The system boundary defines which part of the product life cycle and the associated processes and activities belong to the studied chain. It details which parts of the product life cycle are included or excluded from the analysis and will help to define the structure of the analysis.

A precise definition of the system boundary is important to ensure that all relevant processes are included in the modelled supply chain and that all relevant potential impacts on the environment are appropriately considered.

The system boundary shall be defined following general supply chain logic including all the stages ranging from raw material extraction to the point at which the functional unit is produced. A full LCA therefore would include processing, distribution, consumption and final disposal. The modular approach in the feed production chain is designed to ensure maximum flexibility for the wide variety of feed supply chains. It requires the definition of a number of internal system boundaries, in combination with the related reference unit. In this section, system boundaries have been defined to ensure that the modular approach will not lead to double counting or to gaps in the supply chain. Different internal system boundaries can be selected, but the practitioner shall ensure that there be a good fit between the downstream boundary of the first stage and the upstream boundary of the next one.

The modular approach for feed production has been described in Section 7.2. Four stages have been identified: feed production, processing, compound feed production and farm.

The boundary of any product shall include all relevant processes.

8.4.2 System boundaries of the feed production stage

The feed production stage encompasses plant-based materials via crop cultivation and non-plant materials mainly of animal origin (dairy and slaughter products, fish from aquaculture and wild catch) and of non-biogenic origin. Upstream and downstream system boundaries for the biogenic and non-biogenic materials are shown in Table 1.

The feed production stage does not only have a “chain” boundary, but also a time boundary. The time boundary is defined by the length of the production cycle that is being examined. This is important for feed products where multiple harvests per year pertain, such as multiple cuts of grass from pasture or alfalfa fields, but also where two or three production cycles of rice are realized per annum.

TABLE 1: UPSTREAM AND DOWNSTREAM BOUNDARIES FOR FEED MATERIALS

Input material	Upstream boundary	Downstream boundary
Plant origin	Production of inputs, including the extraction of raw materials	Field gate
Animal origin, excluding wild catch fish	Production of animals, including all upstream processes as described in the guidelines for livestock systems	System boundary of the livestock production system as defined in the guidelines for these systems
Wild catch fish	Production of inputs, including the extraction of raw materials	Delivery at the port of arrival
Non-biogenic materials	Production of inputs, including the extraction of raw materials	Delivery at the first processing point in the feed production chain

8.4.3 SYSTEM BOUNDARIES OF THE PROCESSING STAGE

The *processing stage* starts when the feed material arrives at the processing plant and ends when processing has been completed, at the storage point, and is ready for transport to the next stage. Input materials originate from the feed production stage. Processes and activities that may occur in this stage include:

- production and use of energy carriers in processing;
- use of chemicals and other raw materials;
- use of natural resources such as water; and
- production and use of energy for internal storage.

In the case of products of animal origin, the distinction between the feed production stage and the processing stage can be artificial, for example, when the preparation of slaughter co-products takes place in the same slaughtering plant. Inputs for the preparation of the co-product for use as a feed material shall be allocated fully to the co-product and shall be considered as a separate process.

8.4.4 SYSTEM BOUNDARIES OF THE COMPOUND FEED PRODUCTION STAGE

The compound feed stage begins with the receipt of either raw or processed feed material at the feed mill and ends when compound feed is placed in storage ready for transportation to the next stage. The input materials in this stage originate from either:

- the feed production stage;
- the processing stage; or
- external origin(in the case of feed additives of non-biogenic origin).

8.4.5 SYSTEM BOUNDARIES AT THE FARM STAGE

The farm stage begins at the receipt of raw, processed or compound feed material and ends with the delivery of the feed materials to the animal's mouth. Input materials in this stage originate from either:

- the feed production stage;
- the processing stage;
- external origin (in the case of feed additives of non-biogenic origin); or
- the compound feed production stage.

In some situations, feed materials (of plant origin) from the previous stage may be sourced from the same farm where they are produced. This is especially the case for grazing where utilization by the animal takes place at the feed production site itself. In this case, the distinction is artificial. However, this distinction is functional in order to develop an analytical framework applicable to all kinds of feed.

8.4.6 TRANSPORT AND TRADE

Feed materials and products are transported to users and may be stored at various points along the supply chain. Transport and the related storage are intermediate steps within the feed production stages, and in some situations traders also play an important role. The upstream and downstream system boundaries depend on the respective stages (Table 2).

Storage shall only be incorporated into the analysis if it is the responsibility of an external entity to the production stage such as a transporter or an intermediate trader.

Examples of processes related to transport and storage that shall be included are:

- production and use of energy for transport between feed chain stages and for the external storage of crops;
- production and maintenance of transport means; and
- production and use of energy for storage at the warehouse.

TABLE 2: UPSTREAM AND DOWNSTREAM BOUNDARIES FOR TRANSPORT AND TRADE BETWEEN TWO CONSECUTIVE STAGES

From stage A to B	Upstream boundary	Downstream boundary
A: feed production **B: processing**	• Field gate (plant products) • The back gate of the slaughterhouse , that is the downstream system boundary of the livestock production system as defined in the guidelines of these systems, (animal products) • Port of arrival (wild catch fish) • Arrival at processing plant (non-biogenic)	• Reception of the feed material at the processing plant
A: feed production **B: compound feed production**	• Field gate (plant products) • The back gate of the slaughterhouse; the downstream system boundary of the livestock production system as defined in the guidelines of these systems (animal products) • Port of arrival (wild catch fish) • Arrival at processing plant (non-biogenic)	• Reception of the (processed) feed material at the feed mill
A: feed production **B: farm**	• Field gate (plant products) • The back gate of the slaughterhouse, the downstream system boundary of the livestock production system as defined in the guidelines of these systems, (animal products) • Port of arrival (wild catch fish) • Arrival at processing plant (non-biogenic)	• Reception of the (processed) feed material and compound feed at the front farm gate
A: processing **B: compound feed production**	• Storage point after the last activity in the processing plant and ready for transport to the next stage	• Reception of the (processed) feed material at the feed mill
A: processing **B: farm**	• Storage point after the last activity in the processing plant and ready for transport to the next stage	• Reception of the (processed) feed material and compound feed at the front farm gate
A: compound feed production **B: farm**	• Storage point after the last activity in the feed mill and ready for transport to the next stage	• Reception of the (processed) feed material and compound feed at the front farm-gate

Scoping analysis

In general, a scoping analysis should be performed in situations where there is no knowledge, or only limited knowledge, about the system or product being assessed. Frequently a scoping analysis based on a relatively rapid assessment of the system can provide valuable insight into areas that may require additional resources to establish accurate information for the assessment. Scoping analysis can be conducted using secondary data to provide an overall estimate of the system impact.

Existing reviews in the literature of the feed production chain indicate that the following factors are important in the assessment of the environmental performance of feed supply chains: In the cultivation stage, crop yields and the inputs of nitrogen from manure and synthetic fertilizers are important, while in the downstream stages energy use is the most important driver.. Depending on the particular supply chain under study, specific hotspots may be identified.

Scoping analysis can be useful in the case of grazing communal land, where little or no information is available. There is no ownership or land tenure, so little information about grass production is available. However, it is well known that inputs to communal pastures are often nil or close to nil.

8.4.7 Criteria for system boundary

Material system boundaries. Which entities and processes are included in this type of assessment? What is the analysed company's sphere of influence? Which entities and processes are excluded from the assessment, and for what reasons? A flow diagram of all assessment processes should be drawn up to show where processes were cut off. It is recommended that for the main transformation steps within the system boundary a material flow diagram be produced and used to factor in all of the material flows.

Spatial system boundaries. How far do substantial environmental, economic and social impacts occur beyond the land owned or directly used by the assessed entity? The LCA of animal feeds shall cover the cradle-to-animal's mouth stage for all feed sources (including raw materials, inputs, production, harvesting, storage, loss and feeding). A Feed LCAs should also include all emissions associated with land use and land-use change. All emissions directly related to inputs and activities in the feed production chain stages shall be included, irrespective of their location.

8.4.8 MATERIAL CONTRIBUTION AND THRESHOLD

In determining whether to expend resources and effort in order to include specific inputs, a 1 percent cut off threshold for mass and energy should be adopted in compliance with ISO 14044. Inputs to the system that represent less than 1 percent of the mass, or less than 1 percent of the energy required for a specific unit process can be excluded safely from the analysis; conversely, an estimate can be made through the scoping analysis (Section 8.2). An exception to this exclusion is made in cases where significant environmental impact is nevertheless associated with a very small mass input. Otherwise, to be compliant with this guidance, a minimum of 95 percent of the impact for each category shall be accounted.

8.4.9 TIME BOUNDARY FOR DATA

The time boundary for data shall be representative of the time period associated with:

- *the length of the production cycle of the products*. This is relevant for crop products. For many crops, the production cycle is one year. For a number of others, especially forages and grasses, multiple crops per year can be harvested from the same fields. In tropical (and humid) regions, two or three production cycles per year can take place. Data shall be collected per production cycle. Averaging for a range of production cycles (e.g. all cuts within one year or all crops within one year) is acceptable; however this shall be explicitly reported. In the case of perennial crops, data shall be collected over the full length of the production period, including the juvenile stage and the final stage when yields are lower than in the adult growth stage.
- *the feed characteristics*. Particularly in the case of grass production, feed characteristics can change during the growing season and between cuts. If this variation is not covered by the approach described above, classification should be made on the basis of seasonal variations.
- *the length of one full cycle of crop rotation*. Many crops grow in a rotation cycle of two or more years. Many crops grow in a rotation cycle of two or more years. The effect of some related inputs and activities, are not necessarily seen immediately, that is in the same year in which the activities take place or when the input is applied; they are released, and utilized, over time. Section 9 on allocation deals with how to allocate resource use and emissions in such cases.
- *perennial crops*. Many perennial crops have a cycle of juvenile growth with low production, an adult stage and a decline period, at the end of which the crop is removed from the field and a new cycle starts or another crop is sown. This, too, will be discussed in the section on allocation inventory.

- *variation between years or production cycles*. Data should be averaged over a longer period. Details will be defined in Section 10.

8.4.10 Capital goods

The production of capital goods (buildings) with a lifetime greater than one year may be excluded in the life cycle inventory; however, this is not the case for the production and maintenance of machinery used in cultivation which should instead be included in the life cycle inventory. Additionally, the operation, occupation or other activities utilizing capital goods shall be taken into account. In the case of studies in which the goal and scope include assessment of alternate systems for which there may be significant differences in infrastructure requirements, capital goods production shall be included.

8.4.11 Ancillary activities

Emissions from ancillary inputs, such as veterinary medicine, servicing, employee commutes, executive air travel, accounting or legal services may be included if relevant. To determine if these activities are relevant, an input-output analysis can be used as a scoping analysis.

8.4.12 Delayed emissions

The PAS2050-2011 approach is recommended, where it is not necessary to visualize all biogenic carbon flows. All emissions associated with products to the primary processing stage are assumed to occur within the time boundary for data, generally of one or more years, and assumed to be part of the short carbon cycle. Therefore they are not taken into account. An exception is the emission of biogenic carbon, occurring in the case of land use and land-use change and in the use of lime and urea.

8.4.13 Carbon offsets

Offsets shall not be included in the carbon footprint. However, they may be reported separately as "additional information".

8.5 Impact categories and characterization methods

For the feed LCA, all impact categories that are qualified as relevant and operational should be covered (Section 2.1). These include: climate change, acidification, eutrophication, land occupation and fossil energy demand (Table 3). For climate change (as well as climate change from land use change), land occupation, and fossil energy demand, the recommended method should be applied. For the other impact categories, Table 3 provides recommendations of possible methods that are often applied in the modelling of the impacts. Table 3 does not, however, cover all available methods and models. Other methods and models may be applied if: a) these have greater local relevance; b) they have scientific underpinning, proven in peer-reviewed scientific publications; and c) are publicly available for other users.

Any exclusion shall be explicitly documented and justified; the influence of such exclusion on the final results shall be discussed in the interpretation and communication stage and reported.

TABLE 3: RECOMMENDATIONS REGARDING IMPACT CATEGORIES AND IMPACT ASSESSMENT METHODS

Impact category	Impact category indicator	Characterization model	Sources and remarks
Climate change	kg CO_2 equivalent	- Bern model - Global Warming Potentials (GWP) over a 100-year time horizon.	IPCC, 2006c
Climate change from LUC to be reported separately	kg CO_2 equivalent	- Bern model - Global Warming Potentials (GWP) over a 100-year time horizon. - Inventory data for areas associated with land use change per land use type and related GHG emission are based on two methods: 1. 20 years depreciation of historical land use change (PAS2050-1:2012) 2. global marginal annual land use change (Vellinga, 2012)	BSI, 2012 PAS2050-1:2012 Vellinga 2013, see annex
Fossil energy demand	MJ (LHV)	- Based on inventory data concerning energy use - Primary energy for electricity production required - No impact assessment method involved	- In several impact assessment methods, such as *Recipe* and Guinee *et al., 2002,* fossil energy demand is either a separate impact category or part of a larger category such as abiotic depletion. In addition, in these impact methods the different energy sources are weighed by their LHV without taking into account the differences in availability and quality of reserves of the specific energy sources.
Land occuparion	m^2per year per land use category (arable land and grassland and location)	- Inventory data - No further impact assessment method involved	
Acidification	Depending on the impact assessment method	Depending on the impact assessment method	- ReCiPe (Goedkoop et al., 2008), ILCD or a regional specific impact assessment method - For US and Japan : Hauschild et al. (2013)
Eutrophication	Depending on the impact assessment method	Depending on the impact assessment method	- ReCiPe (Goedkoop et al., 2008), ILCD or a regional specific impact assessment method - For US and Japan : Hauschild et al. (2013)

9 MULTI-FUNCTIONAL PROCESSES AND ALLOCATION

9.1 General principles

The ISO 14044 standard sets the framework for defining allocation procedures by identifying general starting points and a stepwise approach. The standard states that:

- In the application of this guidance, the following requirements for allocation shall be met: inputs and outputs shall be allocated to different products according to clearly stated procedures that shall be documented and explained..
- The sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation.
- Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of any departure from the selected approach.

A stepwise approach

Step 1: Wherever possible, allocation should be avoided by:

1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes; or

2) expanding the product system to include the additional functions related to the co-products.

Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned among its different products or functions in a way that reflects the underlying physical relationships between them; that is,. they should reflect the way in which the inputs and outputs are changed according to any quantitative changes in the products or functions delivered by the system.

Step 3: Where physical relationships alone cannot be established or used as the basis for allocation, inputs should be allocated among the products and functions in a way that reflects the other relationships between them. For example, input and output data might be allocated among co-products in proportion to the economic value of the products.

Some outputs may be partly co-products and partly waste. In such cases, it is necessary to identify the ratio between co-products and waste since the inputs and outputs shall be allocated to the co-products alone.

Allocation procedures shall be uniformly applied to similar inputs and outputs of the system under consideration. For example, if allocation is made to usable products (e.g. intermediate or discarded products) leaving the system, then the allocation procedure shall be similar to the allocation procedure used for such products when entering the system.

Furthermore, whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach (ISO 2006, p14).

9.2 A decision tree to guide methodology choices

To make these general ISO requirements operational for allocation in the feed production life cycle we applied the ISO steps in three situations:

1) the combined, complex joint production processes, such as those including farms and factories that are subjects of the feed LCA;
2) the allocation procedures for transport; and
3) the allocation procedures for manure application.

In the following sections, we will elaborate on the recommended default methods contained in these guidelines. This default method supports the majority of situations studied by an attributional LCA.

a) Allocation at farms and factories[2]

The ISO stepwise approach is applied on three aggregate steps (Figures 7):

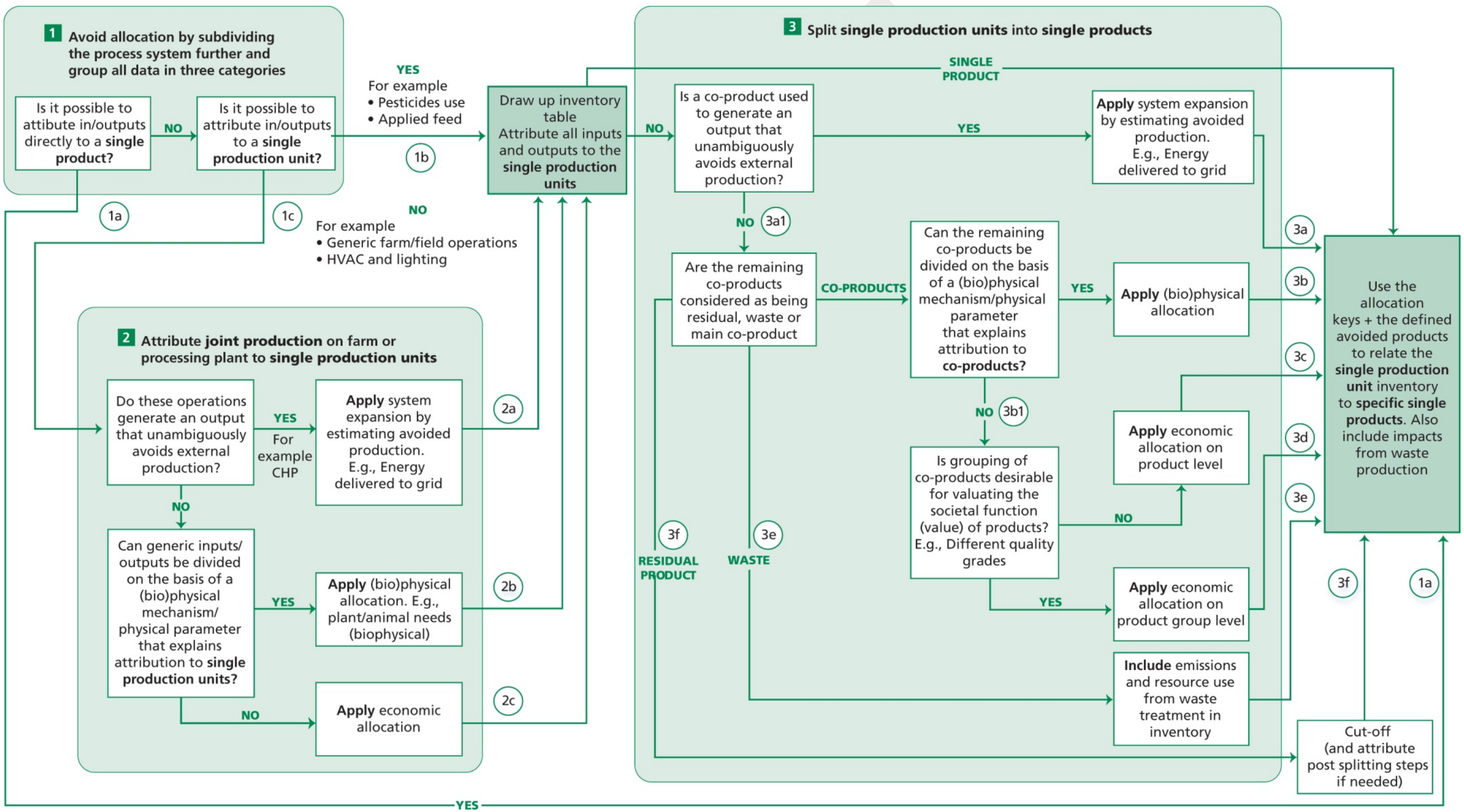
- Step 1 identifies the processes that can be directly allocated to the co-products. This corresponds to the ISO step 1a: *avoid allocation by subdivision*, (Box 1, Figure 7).
- Step 2 applies the subsequent ISO steps (1b, 2 and 3) to allocate inputs and emissions from factory/farm level to production unit level (Box 2, Figure 7); and
- Step 3 applies the ISO steps 1b, 2 and 3, to allocate inputs and emissions from production unit level to co-products level (Box 3, Figure 7).

A production unit is defined here as a group of activities (along with the necessary inputs, machinery and equipment) in a factory or a farm needed to produce one or more co-products. Examples are the crop fields in an arable farm, or the production lines in a factory.

In the process of defining the most suitable allocation approach in a feed LCA, decisions need to be made as to which allocation method to apply where. Furthermore, the status of the co-products needs to be defined more precisely: should they be considered as residue or waste or as a co-product? And finally, if economic allocation is applied, it is necessary to make decisions as to the grouping of co-products. Figure 7 presents the detailed decision tree and principles recommended in the application of allocation process of feed materials. Examples on the application of the decision tree are provided in Section 11 on life cycle inventory

[2] This section also applies to industrial fishing for fishmeal and fish oil.

FIGURE 7: THE DECISION TREE FOR ALLOCATION IN THE FEED PRODUCTION CHAIN



Step 1: Avoid allocation by subdividing and then divide processes and activities into three groups

In the first step "ISO step 1a subdivision", all processes and activities of a farm/factory are divided into three categories:

- flow 1.a. Inputs/activities that should be directly assigned to a co-product, e.g. storage of grains at the farm after harvesting, drying of beet pulp in the sugar factory or drying of oil seed meals after separation.
- flow 1.b. Inputs/activities that should be assigned to production units that can produce single or multiple co-products, e.g. inputs of pesticides, fertilizers, energy inputs of field operations for a crop at an arable farm, feed intake for a specific animal type at an animal farm or energy inputs in a (pre) separation process such as crushing or milling).
- flow 1.c. Inputs/activities of a generic nature in a farm or factory such as manure application for soil quality maintenance on a farm, or, alternatively, heating, ventilation, climate control, internal transport in a factory or farm but which cannot be directly attributed to production units.

All three of these routes are relevant for the feed life cycle.. The inputs and activities of flows 1b and 1c should be further assigned to production units in Step 2.

Step 2: Attribution of joint production to production units.

In tep 2 in Figure 7, the generic processes are to be attributed to production units on the basis of the ISO steps 1b, 2 and 3. The current guidelines provide direction on these steps and on the conditions applied in the selection of the recommended allocation method. The guidelines also provide explicit allocation rules regarding the criteria for decision-making (*the rules are visualized as underlined text*).

System expansion (ISO step 1b) should be applied only on the condition that the avoided production system can be unambiguously determined and where there is little interference with other feed or animal production systems (generates flow 2a in Figure 7).

Unambiguity is well-defined in the case of delivering energy or substances to a grid or network, such as an electricity grid, a gas, and heat or CO_2 network. In this case, it can be assumed that the average impact of production to the grid is avoided[3].

In other cases, when co-products are sold to a broader market, system expansion introduces arbitrary choices and complications. Arbitrary choices are about exactly which product and underlying process are being avoided. The situation becomes even more complex if the avoided product is also a co-

[3] Blonk et al. (2010) show that this is in practice less clear for an electricity grid, raising the question of how, when the grid is fed by multiple production units, the avoided production/consumption mix should be determined, particularly if your type of electricity production is a part of the mix. In PAS2050-2011, a practical approach has been defined by simply stating that the average country production mix should be applied.

product, resulting in additional system effects being introduced that will also need to be modelled. In addition, if other feed or livestock products are involved in the system expansion, they, too, should be accounted for in those LCA's, adding yet another dimension of complexity. Therefore, in the feed guidelines the replacement method has been applied only to situations where the alternative production is very certain, such as for energy production provided to a national grid.

Physical allocation referring to the existence of a physical causality (ISO step 2) to production units is relevant in cultivation for the following three situations:

a. inputs at farm level for basic operations that cannot be unambiguously attributed to specific crops, e.g. capital goods and infrastructure (concrete pavements, fences, sheds) or electricity use for offices and sheds;
b. inputs to the field that are meant to maintain overall field quality and benefit all the crops (for example, by maintaining soil fertility in a rotation scheme by applying manure and other organic fertilizers that provide minerals to the subsequent crops even after the crop of immediate application).
c. Complex multiple cropping systems where plants are cultivated alongside one another in an intercropping system, that is in a single field.

If inputs in a multiple crop production system benefit all crops but are not specifically assigned to all production units, the allocation to crop production shall be based on the nutrient requirements of the crop, that is if sufficient information is available. Otherwise allocation shall be based on the economic value of the crop-production units; except for crop rotation in open field cultivation that is area-based (generates flow 2b, Figure 7).

Application of organic fertilizers (e.g. animal manure, peat products, compost) in agriculture production systems result in emissions that occur within one year and emissions that occur after that year (delayed emissions). Assuming a steady state situation, these delayed emissions are divided among the crop production units in the crop rotation scheme, i.e. those planted and harvested in the year of application. An alternative method is to divide the emissions into:

- emissions that occur in the same year that organic fertilizer is applied should be fully allocated to the crop of application.
- emissions that occur after one year of organic fertilizer application should be allocated to all crops that grow in the year following application.

NOTE: The minimum period of collecting data for open field cultivation is three years. The calculation and allocation of delayed emissions per crop shall be done per year and averaged over three years.

NOTE: If there are multiple yields of a crop within one year, a correction must be made on the total area in the allocation by multiplying the area used for sequential cropping by the number of cropping cycles.

Processing

Similar to cultivation, some of the activities in processing cannot be simply assigned to the production units, e.g. climate control (heating, cooling), lighting, infrastructure etc. Normally, these activities do not have a large contribution and neglecting them may not significantly affect the results.. However, when a relevant contribution is expected to result, data should be collected and a choice for an allocation method needs to be made. Generally, it is possible to select a physical property from among the flow of products being produced for attribution of the generic impacts.

If inputs in a multiple production system benefit all products and cannot be specifically assigned to a single production unit, allocation should be based on a physical property (generates flow 2b in Figure 7).

Step 3: Split single production units into single co-products

The feed guidelines are in line with the overall stepwise ISO approach.

Regarding system expansion (step 1b), the rule described above for attribution to production units applies; only in unambiguous situations of avoidance, such as electricity supply to the grid, should system expansion be applied.

The next step is to define whether the outputs should be considered as residues. Outputs of a production process are considered as residues (flow 3f) if:

- sold in the condition as it appears in the process (before drying and other modifications), contributes very little to the turnover of the company (value of the total flow less than 1%)
- the upstream and production process that produce the output are not deliberately modified for the outputs

Co-products[4] classified as residues should not be considered as "waste" because they are part of a processing or production process, whereas a "waste" is material that is destined for final waste processing (e.g. incineration and land filling).

After residues and waste have been separated from co-products, the practitioner should base his or her decision as to whether physical allocation is possible and logical on the underlying mechanism or properties of the co-products.

[4] Co-products of processing, having a very low value at the moment they arise in the production process, are usually wet by-products (e.g. wet cassava pulp, wet whey, wet citrus pulp, wet potato pulp & potato peels, disposed fruit & vegetables, wet distillers' grain, wet beet pulp, etc.). See Section 11.3.5 for a list of co-products considered as residuals in a baseline assumption.

In most cases, however, there is no simple and consistent physical model available that can be used to attribute environmental impacts to specific co-products. First, in contrast with dairy production, where energy requirements for milk and meat can be separated (IDF, 2010), the inputs in crop production cannot be attributed to crop/plant components, nor to components that are separated in a processing industry. Second, the physical characteristics for which co-products are used for feed vary greatly; some products are used for their energy content, others for their protein content or even specific amino acids, etc.

One could thus consider developing a physical allocation rule for each category of feed (energy rich, protein rich, etc). This, however, would lead to inconsistencies between the attribution rules used for different feed materials, something which is against the ISO recommendations.

In parallel, the price of feed materials seems to be generally correlated to their nutritional value, and in particular with their energy and protein content (www.voederwaardeprijzen.nl).

So, unless the complex physical relationship can be captured in a physical model, economic allocation is the preferred method as it seems to generally provide the best option to allocate the environmental burdens in a consistent manner and on the basis of meaningful relationships.

For external communication or comparison, several alternative allocation options shall be compared as part of a process of sensitivity assessment.

Economic allocation can be applied on several levels of aggregation; for example, often groupings of products that have similar applications takes place so that the basket of co-products is reduced to a few product groups for which an average value can be determined. One example is the dry milling of wheat where an average value for the brans is derived from average sales prices instead of defining bran qualities per batch of flour milling. The slaughtering process also generates a great number of diverse co-products that enter different markets. In practice, these co-products are often grouped together on the basis of the level of legally allowable applications: material, feed, food. When it comes to fresh products that enter the food market, prices are to a great extent determined by consumer perception. However, how meaningful is it to distinguish among different meat cuts or between A and B quality apples? In PAS2050-1 2012, it is recommended not to differentiate beyond a level that exceeds basic functionality and one which is related exclusively to consumer preferences.

Grouping of co-products should be conducted on the basis of their basic functionality.

The attribution allocation process as described above and as visualized in Figure 7 may result eventually in the flows 3a to 3f. A number of examples of economic allocation are given in Section 11.3.5.

9.2.1 ALLOCATION OF TRANSPORT

Since feed products are transported all over the world, the importance of transport in the overall environmental impact can be quite significant. Estimating the environmental impacts of transportation entails two complex allocation issues: how should empty transport – for example when a ship or other means of transport returns empty – be allocated, and, how to allocate (fraction out) the environmental impact of products that are transported together. The allocation of empty transport distance is often incorporated into the background models used for deriving secondary LCI data for transportation by using a 50 percent load factor. However, if primary data for transport is to be derived, the LCA practitioner should make an estimate of the empty transport distance. It is good practice to apply a worst-case estimate here, meaning the inclusion of a 100 percent increase in extra transport for empty return.

Allocation of empty transport kilometres shall be done on the basis of the average load factor of the transport that is under study. If no supporting information is available, it should be assumed that 100 percent additional transport is needed for empty return.

If products are transported by a vehicle, resource use and emissions of the vehicle should be allocated to the transported products. Every means of transport has a maximum load. This maximum load is expressed in tonnage. However the maximum weight can be achieved only if the density of the loaded goods allows for it.

Allocation of transport emissions to transported products shall be done on the basis of physical causality, such as mass share, unless the density of the transported product is significantly lower than average so that the volume transported is less than the maximum load.

9.2.2 ALLOCATION OF MANURE

Manure links the animal and the plant production systems on different levels. An allocation problem arises when the manure leaves the animal farm to be then applied in a plant production system. A comprehensive approach for defining the allocation procedure for manure is given in the LEAP animal production guidelines. For the feed guidelines only the application of manure in cultivation falls within the system boundaries. At this point, the most important question becomes that of defining the upstream life cycle of manure in coherence with the animal guidelines.

The default approach in the LEAP guidelines is to consider manure as a residue co-product (see LEAP Animal Guidelines). Emissions and resource use of manure storage are then allocated to the animal farm. Only transport from the animal farm and application of manure is allocated to the plant production system.

It could happen, however, that manure is defined as a co-product of the animal farm, in which case an environmental burden can be attributed to the manure on the basis of economic allocation.

10 COMPILING AND RECORDING INVENTORY DATA

10.1 General principles

The compilation of the inventory data should be aligned with the goal and scope of the life cycle assessment. The LEAP guidelines are intended to provide LCA practitioners with practical advice for a range of potential study objectives. This is in recognition of the fact that studies may wish to assess animal feed supply chains ranging from individual farms, to integrated production systems, to regional or national scale, or to a sector level. When evaluating the data collection requirements for the project, it is necessary to consider the influence of the project scope. In general these guidelines recommend collection of primary activity data (Section 10.2.1) for foreground processes, those processes generally being considered as under the control or direct influence of the study commissioner; however, it is recognized that for projects with larger scope, such as sectoral analyses at the national scale, the collection of primary data for all foreground processes may be impractical. In such situations, or when an LCA is conducted for policy analysis, foreground systems may be modelled using data obtained from secondary sources such as national statistical databases, peer-reviewed literature or other reputable sources.

An inventory of all materials, energy resource inputs, outputs (including products, co-products and emissions) for the product supply chain under study shall be compiled. The data recorded in relation to this inventory shall include all processes and emissions occurring within the system boundary of that product.

As far as possible, primary inventory data shall be collected for all resource use and emissions associated with each life cycle stage included in the defined system boundaries. For processes where the practitioner does not have direct access to primary data (i.e. background processes), secondary data can be used. Data collected directly from suppliers should be used for the most relevant products supplied by them when possible. If secondary data are more representative or appropriate than primary data for foreground processes (to be justified and reported), secondary data shall also be used for these foreground processes.

For agricultural systems, two main differences exist compared to industrial systems. Firstly, production may not be static from year to year, and secondly, some inputs and outputs are very difficult to measure. Consequently, the inventory stage of an agricultural LCA is far more complex than most industrial processes, and may require extensive modelling in order to define the inputs and outputs from the system. For this reason agricultural studies often rely on a far smaller sample size and are often presented as 'case studies' rather than 'industry averages'. For agricultural systems, many foreground processes must be modelled or estimated rather than measured. Assumptions made during the inventory development are critical to the results of the study and need to be carefully explained in the methodology of the study. In order to clarify the nature of the inventory data, it is useful to differentiate between 'measured' and 'modelled' foreground system LCI data. For a farm operation, measured foreground data would include fuel use and livestock numbers, while modelled foreground data would include feed intake during grazing/browsing and manure quantity.

The LCA practitioner shall demonstrate that the following aspects in data collection have been taken into consideration when carrying out the assessment (adapted from ISO14044):

1. **Representativeness**: qualitative assessment of the degree to which the data set reflects the true population of interest. Representativeness covers the three following dimensions:
    1. time-related representativeness: age of data and the length of time over which data was collected;
    2. geographical representativeness: geographical area from which data for unit processes was collected to satisfy the goal of the study; and
    3. technology representativeness: specific technology or technology mix;
2. **Precision**: measure of the variability of the data values for each data expressed (e.g. standard deviation);
3. **Completeness**: percentage of flow that is measured or estimated;
4. **Consistency**: qualitative assessment of whether the study methodology is applied uniformly to the various components of the analysis;
5. **Reproducibility**: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the study;
6. **Sources** of the data;
7. **Uncertainty** of the information (e.g. data, models and assumptions).

For significant processes, LCA practitioner shall document the data sources, the data quality, and any efforts made to improve data quality.

For processes with a significant impact, LCA practitioners shall document the data sources, the data quality, and any efforts made to improve data quality.

10.2 Requirements and guidance for the collection of data

Two types of data may be collected and used in performing LCAs:

- Primary data: defined as directly measured or collected data representative of processes at a specific facility or for specific processes within the product supply chain.
- Secondary data: defined as information obtained from sources other than direct measurement of the inputs/outputs (or purchases and emissions) from processes included in the life cycle of the product (PAS 2050:2011, 3.41). Secondary data are used when primary data are not available or it is impractical to obtain them. Some emissions, enteric fermentation in the rumen of animals, are calculated from a model, and are therefore considered secondary data.

For projects where significant primary data is to be collected, a data management plan is a valuable tool for managing data and tracking the process of LCI data set creation, including metadata documentation. The data management plan should include (Bhatia *et al.*, 2011, Appendix C):

- A description of data collection procedures;
- data sources;
- calculation methodologies;
- data transmission, storage and backup procedures; and
- quality control and review procedures for data collection, input and handling activities, data documentation and emissions calculations.

The recommended hierarchy of criteria for acceptance of data is:

- primary data collected as part of the project and that have a documented Quality Assessment (Section 10.3);
- data from previous projects that have a documented Quality Assessment;
- data published in peer-reviewed journals or from generally accepted LCA databases that are regarded as reliable sources of information;
- data presented at conferences or otherwise publicly available (e.g., internet sources); and
- data from industrial studies or reports can be considered.

10.2.1 Requirements and guidance for the collection of primary activity data

Primary activity data must be used for processes under the ownership or control of the farmer, company or consultant completing the inventory.

In general, primary data shall, to the fullest extent feasible, be collected for all foreground system processes (here defined as those processes under the direct control of or significantly influenced by the study commissioner) and for the main contributing sources to GHG emissions. All four stages in the feed chain including the transport and trade link are considered as being foreground processes.

The practicality of measured data for all foreground processes is also related to the scale of the project. As an example, if a national scale evaluation of the feed sector is planned, it is impractical to collect farm level data from all producers. In such a case, aggregated data from national statistical databases or other sources (e.g., trade organizations) may be used for foreground processes. But in every case, documentation of the data collection process and accurate data quality documentation shall be incorporated into the report to ensure suitability with the study goal and its scope.

Relevant specific data that is representative of the product or processes being assessed shall be collected. To the greatest extent possible, recent data shall be used, such as current data from industry stakeholders. Collected data should respect geographic relevance (e.g. for crop yield in relation to climate and soils) and conform to the defined goal and scope of the analysis. Each data source should be acknowledged, and uncertainty in the data quality noted.

In some cases, data may be available directly from the relevant literature, such as that presented in primary referenced journal articles albeit adjusted for units or scale, if necessary). The recommended hierarchy of the criteria for the acceptance of data is:

- primary data collected as part of the project and that have been awarded a documented quality assessment (Section 10.3); and
- data from previous projects that have been awarded a documented quality assessment (Section 10.3).

10.2.2 GUIDANCE FOR THE COLLECTION AND USE OF SECONDARY DATA AND DEFAULT DATA

Secondary data refers to life cycle inventory data sets that generally are available from existing third-party databases, government or industry association reports, peer-reviewed literature, or other sources. Such data is normally used for background system processes, such as electricity or diesel fuel which may be consumed by foreground system processes. When using secondary data, it is necessary to selectively choose the data sets that will be incorporated into the analysis. Specifically, life cycle inventory for goods and services consumed by the foreground system should be geographically and technically relevant.

Where primary data is unavailable and where inputs or processes make a minor contribution to total GHG emissions, secondary or default data may be used. However, geographic relevance should be taken into consideration. For example, if default data is used for a minor input such as a pesticide, the source of production should be determined and a transportation component added to calculation of the emissions in order to account for its delivery from site of production to site of use. Similarly, where there is an electricity component related to an input, a relevant electricity emission factor for the country or site of use should be used that accounts for the relevant energy grid mix. All secondary and generic data should satisfy the following requirements:

- They shall be as current as possible and collected within the past 5-7 years.
- They should be used only for processes in the background system. When available, sector-specific data shall be used instead of proxy LCI data.
- They shall fulfill the data quality requirements specified in this guide (Section 10.3).
- They may only be used for foreground processes if specific data are unavailable or the process is not environmentally significant. However, if the quality of available specific data is considerably lower and the proxy or average data sufficiently represents the process, then proxy data shall be used.

Secondary data shall be sourced from:

- LCA databases as mentioned in Table 4;
- databases other than those presented in Table 4 as long as credible documentation of the data is available and published;
- peer-reviewed publications in scientific journals; and
- peer-reviewed and validated reports that are publicly available from research institutes, private sector organizations or industries.

When secondary data are used, the LCA user shall make explicit reference to the data source.

TABLE 4: DATABASES THAT CAN BE USED IN LCA ANALYSIS FOR COLLECTING SECONDARY DATA

Name	Database/ Software	Countries/Regions represented	Salient features and access points
ELCD	Database (web-based)	EC	- Good data for transport and energy production and some chemicals and materials - Free http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm
Ecoinvent	Database as such and implemented in LCA software (Simapro)	Global	- Most used database in LCA, limited amount of feed raw material data - Free for Simapro users http://www.ecoinvent.ch/
Agri-footprint LCI data (includes most Feedprint data)	Database implemented in LCA software (Simapro)	Global	- LCI database that includes full inventory data expansion of Feedprint data - Free for Simapro users - To be released in May 2014 http://www.agri-footprint.com http://www.pre-sustainability.com/
USDA LCA Commons	Database (web-based)	U.S.	- Excellent US field crop production (corn, cotton, oats, peanuts, rice, soybeans, and durum, other spring, and winter wheat in USDA Program States from 1996-2009) - Free http://www.lcacommons.gov
U.S. Life-Cycle Inventory (LCI) Database	Database (web-based)	U.S.	- Database providing individual gate-to-gate, cradle-to-gate and cradle-to-grave accounting of the energy and material flows into and out of the environment that are associated with producing a material, component, or assembly in the U.S. http://www.nrel.gov/lci/
JEMAI CFP Program	Database (web-based)	Japan, with limited coverage for other Asian countries	- Database originated by the Japanese government and since April 2012, managed by the Japan Environmental Management Association for Industry (JEMAI) which has taken over the responsibility to maintain the Japanese CFP scheme - Free http://www.cfp-japan.jp/english/ (English site has limited information) http://www.cfp-japan.jp/calculate/verify/data.html
GaBi	Software (GUI based) with database	Global	- PE International in partnership with Department of Life Cycle Engineering at Univ. of Stuttgart developed GaBi LCA software. - Paid http://www.gabi-software.com

10.2.3 Guidance on data sources for feed additives

Feed additives can play an essential role in improving animal performance and animal health. The production of feed additives differs from general feed production as many additives are derived from fossil and mineral materials and on an industrial basis. Therefore, the feed guidelines in this report do not provide guidelines for the calculation of the environmental impact of additive production. Currently, a methodology on the production of feed additives is still lacking. Initial work has been done by the International Feed Industry federation (IFIF) and the EU association of Specialty Feed Ingredients (FEFANA); however, this project is still in its initial stages.

The LCA practitioner shall, where available, first source data from internationally accepted databases. A number of "simple" feed additives such as salt, chalk and other minerals can be found in the databases presented in Table 4. In the absence of information on feed additives in these databases (which is likely the case for the organic compounds such as amino-acids, enzymes, etc.), the LCA practitioner should look for reviewed and/or validated publications, including papers published in scientific journals, reports from consultants or research institutes, or reports from industry.

Additional to the environmental impact of the feed additives, the effect of the additive on animal performance and feed conversion ratio must be taken into account in order to calculate the impact of applying additives along the chain as a whole.

10.2.4 Approaches for addressing data gaps in LCI

Data gaps exist when there is no primary or secondary data available that is sufficiently representative of the given process in the product's life cycle. LCI data gaps can result in inaccurate and erroneous results (Reap *et al.*, 2008). When missing LCI is set to zero, the result is bias towards lower environmental impacts (Huijbregts *et al.*, 2001).

Several approaches have been used to bridge data gaps, but none are considered standard LCA methodology (Finnveden *et al.*, 2009). As much as possible, the LCA practitioner shall attempt to fill data gaps by collecting the missing data. However, data collection is time-consuming and expensive, and is often not feasible. The following sections provide additional guidance on filling data gaps with proxy and estimated data.

The use of proxy data sets – background LCI data sets which are the most similar process/product for which data is available – is common. This technique relies on the practitioner's judgment, and is therefore, at least arguably, arbitrary (Huijbregts *et al.*, 2001). Using the average of several proxy data sets has been suggested as a means to reduce uncertainty compared to the use of a single data set (Milà-i-Canals et al., 2011). Milà-i-Canals et al. (2011) also suggest that extrapolation from one data set to bridge the gap may also be used. For example, Adapting an energy emission factor for one region to another with a different generation mix is another example. While use of proxy datasets is the simplest solution, it also has the highest element of uncertainty. Extrapolation methods require expert knowledge and are more difficult to apply, but provide more accurate results.

For countries where environmentally extended economic input-output tables have been produced, a hybrid approach can also be used as a means of bridging data gaps. In this approach the monitor value of the missing input is analysed through the input-output tables and then used as a proxy LCI data set. This approach is of course subject to uncertainty and has been criticized (Finnveden *et al.*, 2009).

Any data gaps shall be filled using the best available secondary or extrapolated data. The contribution of such data (including gaps in secondary data) shall not account for more than 20 percent of the overall contribution to each emission factor impact category considered.

In line with the guidance on data quality assessment, any assumptions made in filling data gaps, along with the anticipated effect on the product inventory final results, shall be documented. If possible, the use of such gap-filling data should be accompanied by data quality indicators, such as a range of values or statistical measures that convey information about the possible error associated with using the chosen method.

10.3 Data quality assessment

LCA practitioners are required to assess data quality by using data quality indicators. Generally, data quality assessment can indicate how representative the data are as well as their quality. Assessing data quality is important for a number of reasons: improving the inventory's data content, for proper communication and interpretation of results, as well as informing users about the possible uses of the data. Data quality refers to characteristics of data that relate to their ability to satisfy stated requirements (ISO14040:2006). Data quality covers various aspects, such as technological, geographical and time-related-representativeness, as well as completeness and precision of the inventory data. This section describes how the data quality shall be assessed.

10.3.1 Data quality rules

Criteria for assessing LCI data quality can be structured by representativeness (technological, geographical, and time-related), completeness (regarding impact category coverage in the inventory), precision/uncertainty (of the collected or modelled inventory data), and methodological appropriateness and consistency. Representativeness addresses how well the collected inventory data represents the "true" inventory of the process for which they are collected regarding technology, geography and time. For data quality, the representativeness of the LCI data is a key component and primary data gathered shall adhere to the data quality criteria of technological, geographical, and time-related representativeness. Table 5 presents a summary of requirements for data quality. Any deviations from the requirements shall be documented. Data quality requirements shall apply to both primary and secondary data. For LCA studies using actual farm data and targeted at addressing farmer behaviour, ensuring that farms surveyed are representative and the data collected is of good quality and well managed is more important than detailed uncertainty assessment.

TABLE 5: OVERVIEW OF REQUIREMENTS FOR DATA QUALITY

Indicator	Requirements/ data quality rules
Technological representativeness	• The data gathered shall represent the processes under consideration.
Geographical representativeness	• If multiple units are under consideration for the collection of specific data, the data gathered shall, at a minimum, represent a local region such as EU-27. • Data should be collected respecting geographic relevance to the defined goal and scope of the analysis.
Temporal representativeness	• Specific data gathered shall be representative for the past 3 years and for 5 to 7 years for secondary data sources. • The representative time period on which data is based shall be documented.

10.4 Uncertainty analysis and related data collection

Data with high uncertainty can negatively impact the overall quality of the inventory. The collection of data for the uncertainty assessment and understanding uncertainty is crucial for the proper interpretation of results as well as reporting and communication (Section 12).

The following guidelines shall apply for all studies intended for distribution to third parties, and should be followed for internal studies intended for process improvement:

- Whenever data is gathered, data should also be collected for the uncertainty assessment.
- Gathered data should be presented as a best estimate or average value, with an uncertainty indication in the form a standard deviation (where plus and minus twice the standard deviation indicates the 95% confidence interval if data follow a normal distribution.
- When a large set of data is available, the standard deviation should be calculated directly from this data. For single data points, the bandwidth shall be estimated. In both cases the calculations or assumptions for estimates shall be documented.

10.4.1 Inter- and Intra-Annual Variability in emissions

Agricultural processes are highly susceptible to variations in weather patterns year-to-year. This is particularly true for crop yields, but may also affect feed conversion ratios when environmental conditions are severe enough to have an impact on an animal's performance. Depending on the goal and scope definition for the study, additional information may be warranted such that either seasonal or inter-annual variability in the product system efficiency can be captured and identified.

11 LIFE CYCLE INVENTORY

11.1 Overview

This section describes the key steps and requirements in quantifying emissions and in resource use of feed supply chains. The selection of life cycle inventory modelling, including the decisions on which data to collect, depends largely on the goal and scope of the study. The Life Cycle Inventory (LCI) analysis phase involves the collection and quantification of inputs and outputs throughout the life cycle stages covered by the system boundary of the individual study. This typically involves an iterative process (as described in ISO 14044: 2006), with the first steps involving data collection using the principles as outlined in Section 10.1.

The subsequent steps in this process involve the recording and validation of the data; relating the data to each unit process and reference unit (including allocation for different co-products); and the aggregation of data, ensuring that all significant processes, inputs and outputs are included within the system boundary.

In many instances, inventory data are not the result of direct measurements but are a combination of activity related measurements (primary activity data) as well as emission factors or parameterized emission factors (calculation models). This is the case for emissions of the three most important greenhouse gases (CO_2, N_2O and CH_4), or emissions of ammonia, nitrate, and phosphorus in cultivation, as well as for many of the combustion processes in all process stages.

Data collection can be a very laborious and hence costly process, especially in situations where it is not common practice.

Feed production chains are sometimes long and complex and may be limited to some specific stages. This section describes the inventory process for all stages and situations. For example, in extensive farming systems, using low external inputs, which means relying on home grown feed, only a specific selection of the guidelines has to be used. A stepwise approach in the life cycle modelling of the feed supply chain is recommended, starting with the flow chart in Figure 8.

The assessment of feed supply chains may be conducted as part of the analysis of the livestock system or as a stand-alone assessment of the feed chain. If the feed inventory is part of a livestock system analysis, then the goal and scope of that analysis are also valid for feed. On the other hand, if the analysis is limited to the production of a single feed or a compound feed and does not take the use of the feed into account, then goal, scope and methodology (such as system boundaries and impacts) needs to be be defined.

The goal and scope of the analysis affects data collection along with the quality of the required data. Primary data can be easily obtained for crop production, whereas for an analysis at sector level, data can be obtained from secondary sources such as statistical databases and other high-quality sources.

In the case of a hotspot analysis, the need for primary data is less when compared to a study geared at the comparison of farming systems or one with a benchmarking goal. The Product Environmental Footprint Guide of the European Commission demands that high data quality be required in the case of a high contribution to environmental impacts. This, however, is not related to goal and scope.

In case feed is part of the analysis of a livestock system, the process starts with a breakdown of the animals ration into single feed products. For every (single or compound) feed product used, the LCI data shall be collected in accordance with the goal and scope of the analysis.

After selecting the feed products for analysis, a breakdown per feed product needs to be factored into the various stages in the supply chain on the basis of the modular approach described in Section 7.2. The following stages are discussed in this chapter:

- *Cradle-to-gate stage* encompasses the analysis of the primary production of the feed materials from plant origin.
- *Gate-to-gate stage* involves a partial assessment of processes or activities within a specific production unit. A key condition is that the information about the upstream emissions of the previous phase(s) must have been made available by the supplier. In the event primary data on the upstream processes is lacking, secondary data shall be collected.
- *Transport and trade stage* is generally an intermediate step between the other stages and is discussed later in this chapter.

When stages are not used in the production chain of a feed or when transport and trade is minimal (e.g. situations in which feed is manually carried from the field to the farm), they can be omitted. The final result at this point is a table or list of feed products showing all the relevant stages per feed product as shown in Table 6.

TABLE 6: EXAMPLE OF LIST OF FEED PRODUCTS AND PER FEED PRODUCT THEIR RELEVANCE AND THEIR STAGES IN THE PRODUCTION CHAIN

Feed	Relevant	Cultivation	T&T	Processing	T&T	Compounding	T&T	Farm
A	Yes	X						X
B	Yes	X	X	X	X	X	X	X
C	Yes	X		X				X

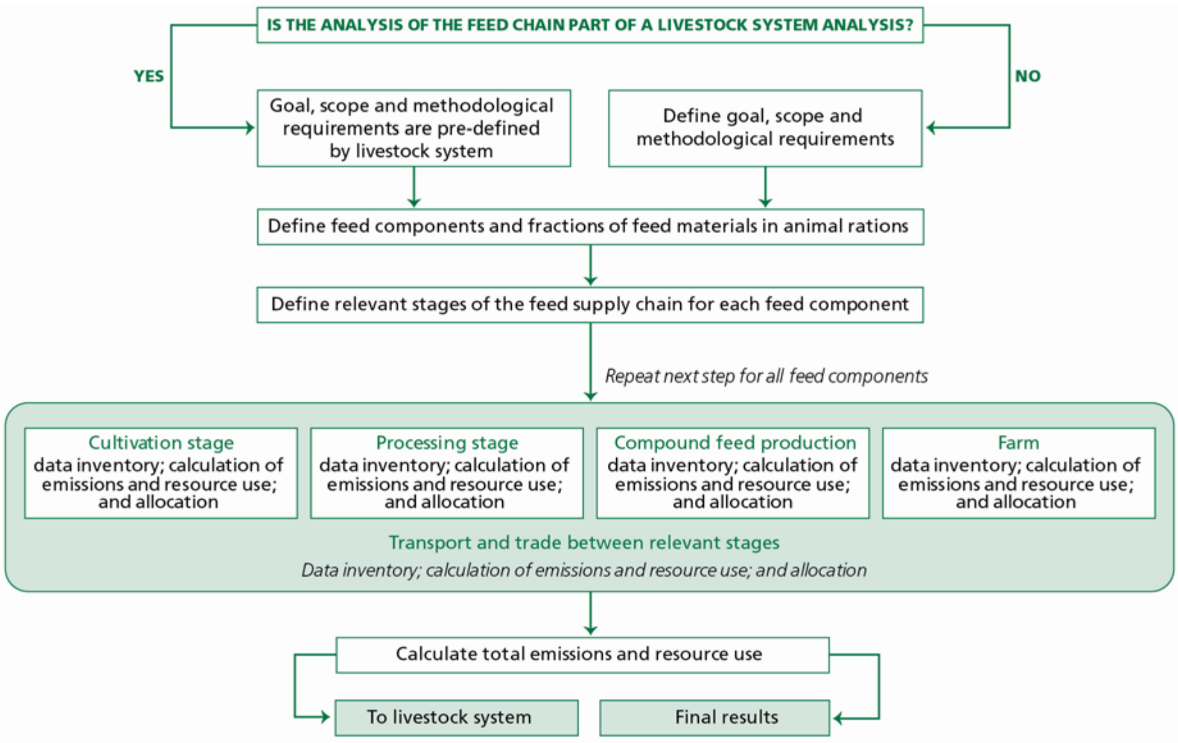
After making the breakdown of the production chain per feed product into a list of feed products and their relevant stages, the following steps in the flow chart are applied to each individual feed product. In every stage of the chain, the first step is to define an inventory of inputs, resource use, outputs and relevant emissions factors. The type of activity data, resource use, emission factors and secondary LCI data to be collected is partly defined by the goal and scope of the study. For example, if the focus of the assessment is only on one environmental impact, such as climate change, the data inventory can be limited to the relevant inputs and emission factors. The second step in every stage of the chain is the calculation of the emissions and resource use of all inputs, based on the model shown here:

$$Emissions\ or\ resources\ use\ = input\ * EF\ or\ RUF$$

(EF = Emission Factor; RUF = Resource Use factor)

A factor can refer to an LCI data point or can be calculated based on a model. The detailed inventory process is described per stage.

FIGURE 8: FLOW CHART TO ANALYSE THE FEED SUPPLY CHAIN



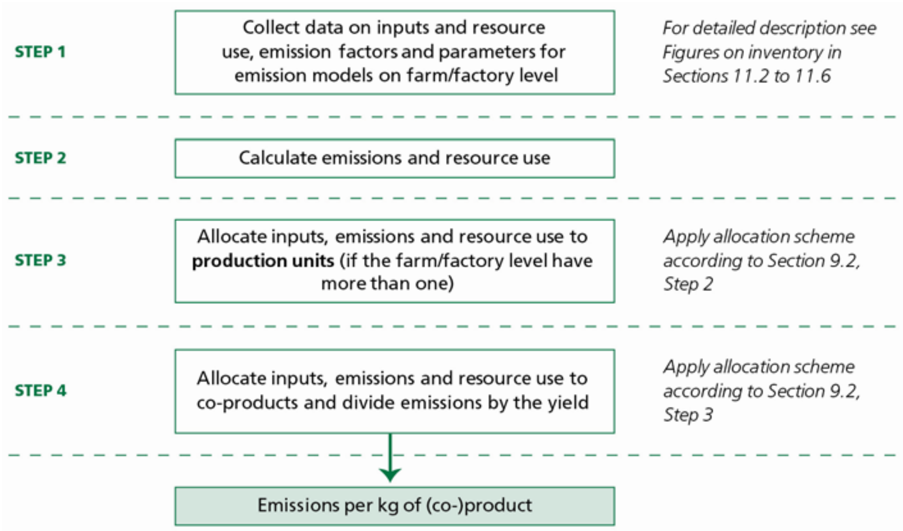
For each stage along the feed chain, four main steps needed (Figure 9):

- **Step 1**: setting up the inventory, which encompasses all inputs, resources and output, but also the inventory of the relevant emission factors;
- **Step 2**: calculation of emissions and resource use;
- **Step 3**: allocation of emissions and resource use to production unit and cycle as based on general allocation principles and the related flow chart as seen in section 10; and
- **Step 4**: allocation of emissions per production unit and cycle to (co-)products.

The final result is a list of emissions per unit of product and per unit of reference flow.

These four steps will be discussed in Sections 11.2 (cultivation), 11.3 (processing), 11.4 (compound feed production), 11.5 (farm), and 11.5 (transport and trade).

FIGURE 9: STEPS IN THE INVENTORY AND EMISSIONS CALCULATION PER STAGE OF THE FEED PRODUCTION CHAIN



11.2 Cradle-to-Gate assessment cultivation

11.2.1 DESCRIPTION OF THE CULTIVATION SYSTEM

The cultivation system on a farm consists mostly of a number of crop production fields upon which one or more different crops are grown.

Crops can be classified into:

- annual crops with one complete production cycle in one year[5];
- crops with multiple complete production cycles per year, e.g. two consecutive rice crops or the production of maize and soybeans in one year;
- perennial crops with one harvest per year (in their productive stage) such as oil palm fruit and sugar cane; and
- perennial crops with multiple harvests per year, e.g. permanent pastures, alfalfa, etc. In these guidelines grass is considered a perennial crop.

In addition, crops may be cultivated as:

- a single crop per field, in a rotation with a number of other crops; or
- multiple crops per field, as e.g. alley cropping, even with combined perennial and annual crops cultivated in one field.

[5] The production cycle can take place in 2 calendar years but is normally attributed to the year when the crop is yielded.

Moreover, crops are often part of a multi-annual rotation system with multiple crops. Crop rotation is often practiced for reasons of pest and weed control and for the transfer of valuable nutrients from one crop to another (e.g., with the cultivation of leguminous crops).

Inputs and resources to maintain the production system may take place at farm level, but also at field level. To an extent, these inputs and resources are designed to facilitate the process of crop rotation and in subsequent years will benefit other crops. Examples include the transfer of fixed nitrogen from leguminous crops to a subsequent crop, and the long term effects of applied animal manure. In the case of multiple harvests per year, part of the inputs and resource use can also be applied only once and yet benefit multiple harvests in the same year, e.g., fertilizer application in spring, or sward preparation after winter. There will also be activities that are specific to the field and the production cycle, e.g., the application of synthetic fertilizer for wheat production. At harvesting, some activities can be specific at field level, such as harvesting and threshing. The baling of wheat straw can also be considered a field specific activity at the product level.

Dealing with variability in crop production cycles

Cultivation is strongly related to weather conditions such as radiation, temperature and rainfall, with a broad resulting variation between production cycles. To deal with the variation between production cycles, in accordance with clause 7.6 of PAS 2050, cultivation data shall be collected over a period of time sufficient to provide an average assessment of the emissions and resource use associated with the inputs and outputs that will offset fluctuations due to seasonal differences. In many cases, one year will be a sufficient period.

This shall be undertaken as set out below in points a) to c)[6][7][8]:

a) For annual crops, an assessment period of 3 years shall be used that is based on a three-year rolling average of emissions. This is done to offset differences − from weather variation or pests and diseases − in crop yields that are related to fluctuations in growing conditions over the period.

Where data covering a three-year period is not available , for example, where new production systems (e.g. new greenhouses, newly cleared land, or a shift to another crop) are involved, the assessment may be conducted over a shorter period, but this shall not be less than 1 year.

[6] The underlying assumption in the cradle-to-gate GHG emissions assessment of agricultural products is that the inputs and outputs of the cultivation under study are in a ‘steady state’, which means that all development stages of perennial crops (regardless of the different quantities of inputs and outputs) shall be proportionally represented during the time-period under consideration. The advantage of this approach is that inputs and outputs pertaining to a relatively short period can be used for the calculation of the cradle-to-gate GHG emissions from the perennial crop product. Studying all development stages of an agricultural perennial crop can have a lifespan of 20 years and more (e.g. in the case of palm fruit).

[7] The assessment of perennial plants and crops should not be undertaken until the production system actually yields output.

[8] Averaging over three years can best be done by first gathering annual data and calculating the GHG emissions per year and then determining the three years average.

b) For perennial plants (including entire plants and edible portions of perennial plants) a steady state situation (i.e. where all development stages are proportionally represented in the studied time period) shall be assumed and a three-year rolling average shall be used to estimate inputs and outputs.

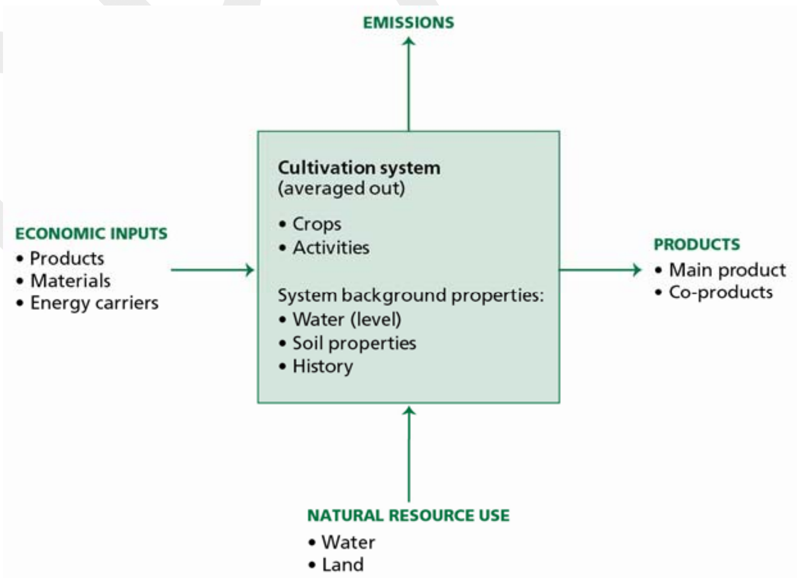
   Where the diverse stages in the cultivation cycle are known to be disproportionate, a correction shall be made by adjusting the crop areas allocated to different development stages in proportion to the crop areas expected in a theoretical steady state. The application of such a correction shall be justified and documented.

c) For crops that are grown and harvested in less than one year (e.g. grass or alfalfa produced within 6 to 12 weeks), data shall be gathered in relation to the specific time period for the production of a single crop from at least three recent consecutive cycles.

11.2.2 Relevant inputs, resource use and emissions during cultivation

Although there are many variations in the cultivation systems, the basic principles of the inventory of inputs, resources and outputs and the calculation of the emissions are relatively simple and are shown in Figure 10.

FIGURE 10: AN OVERVIEW OF THE CULTIVATION SYSTEM AND ITS INPUTS AND OUTPUTS



However, the list of inventory data, as shown in Figure 11, is long. Economic inputs will have different environmental impacts. Section 2.1 defines the impact categories covered by these guidelines. The emissions that play a key role in the various impact categories are summarised in

Table 7. For example, climate change impacts (GHG emissions) in agriculture can originate from carbon dioxide, nitrous oxide or methane.[9] Emissions for these three gases are associated with the production and use of various inputs as well as with resource use such as land use and land use change.

The goal and scope of the study will determine which emissions have to be calculated. When the feed chain analysis is part of a livestock system analysis, only greenhouse gas emissions and fossil fuel use are relevant. In case of a stand-alone feed chain analysis, other environmental impacts may be relevant and additional emissions have to be calculated as well.

TABLE 7: OVERVIEW OF IMPACT CATEGORIES, RELEVANT EMISSIONS AND THEIR SOURCES IN THE CULTIVATION STAGE

Impact category	Emission/ Resource use	Source (activity/input)
Climate change	CO_2	• Production and use of fossil materials (fuels, lime, carbon in Urea, etc.) • Land use change: CO_2 from conversion of (previous) above ground or below ground biomass • Land use: C from soil due to soil management • Peat soils: C from soil due to ground water management
	N_2O	• From fertilizer production and application, from manure application, from crop residues • from crop residues
	CH_4	• from burning of biomass • from anaerobic soil processes (e.g. rice) • from anaerobic processes of waste treatment on farms (a.o. palm oil effluent) • from upstream processes
Acidification	NH_3	• from N application (a fraction that volatizes)
	SO_X	• from upstream processes, mostly fuel combustion
	NO_x	• from upstream processes, mostly fuel combustion
Eutrophication	NH_3	• from N -application (a fraction that volatizes)
	NO_x	• from upstream processes, mostly fuel combustion
	N to soil	• from fertilizer and manure application
	N to water	• from fertilizer and manure application
	P to water	• from fertilizer and manure application
Fossil energy demand	MJ (LHV)	• Use of all kinds of fossil fuels
Land occupation	M2	• Land requirement for all kind of activities

[9] Cooling agents can have significant contribution to GHG emissions and shall be included as well. If not taken into account, the LCA practitioner shall document and justify the exclusion of these emissions.

FIGURE 11: INVENTORY FLOW CHART FOR CULTIVATION

PRIMARY ACTIVITY DATA AND EMISSION MODEL PARAMETERS	PRIMARY ACTIVITY DATA AND EMISSION MODEL PARAMETERS
Input of seed plant material (kg/ha)	LCI should include list of elementary flows as mentioned in *Section 11.2.3*
Input of manure (kg N/ha, volume or weight/ha, method of application	• To calculate N emissions (N_2O, NH_3, NO_x) from application apply factors or models in accordance to goal and scope • If a more detailed approach other than IPCC Tier 2 is applied, check consistency with other data points in the inventory • Emissions and resource use of manure transport can be calculated by combining volume or weight and transport distance with LCI data per ton-km
Input of N from synthetic fertilizer (kg N/ha, type)	• To calculate N emissions (N_2O, NH_3, NO_x) from application apply factors or models in accordance to goal and scope • If a more detailed approach other than IPCC Tier 2 is applied, check consistency with other data points in the inventory
Input of P from synthetic fertilizer (kg/ha, type)	• To calculate P application apply baseline fate model in LCA impact model or use specific fate modelling dependent on goal and scope of study • If data no quality data on emissions and resource use is available see *Table 4, Section 10.2.2* for guidance on secondary data
Input of K from synthetic fertilizer (kg/ha, type)	• If data no quality data on emissions and resource use is available see *Table 4, Section 10.2.2* for guidance on secondary data
Input of peat to soil	• To calculate CO_2 and N_2O emissions from application, apply factors or models in accordance to goal and scope • If a more detailed approach other than IPCC Tier 2 is applied, check consistency with other data points in the inventory
Input of lime (kg/ha, type) Convert to average annual application	• To calculate CO_2 emissions from application, apply factors or models in accordance to goal and scope • If a more detailed approach other than IPCC Tier 2 is applied, check consistency with other data points in the inventory • If data no quality data on emissions and resource use is available, see *Table 4, Section 10.2.2* for guidance on secondary data
Input of pesticides (kg/ha, type) Convert to a.i.	• If data no quality data on emissions and resource use Is available, see *Table 4, Section 10.2.2* for guidance on secondary data
Fuel use (litres/hectare, type)	• If data no quality data on emissions and resource use is available, see *Table 4, Section 10.2.2* for guidance on secondary data
Machine use (hours, type)	• Per machine type: average fuel consumption/hour; • For production and maintenance: If data no quality data on emissions and resource use is available, see *Table 4, Section 10.2.2* for guidance on secondary data
Input N from crop residues (kg N/ha, crop residue management practises)	• To calculate N amounts (kg/ha) N, emissions (N_2O, NH_3, NO_x) from application apply factors or models in accordance to goal and scope • If a more detailed approach other than IPCC Tier 2 is applied, check consistency with other data points in the inventory
Land use and land-use change • Type: arable, grassland and paddy rice • Soil type: mineral or organic soil, drainage depth • History: land use change, country of cultivation	• Type of land use and soil type: to calculate emissions (CO_2 and N_2O), apply models and factors in relation to goal and scope • For paddy rice, if a more detailed approach other than IPCC Tier 2 is applied, check consistency with other data points in the inventory
Crop yield (kg/ha, co-products)	• Gross field area, calculate or assess in relation to goal and scope • Co-products: measure net yield and storage losses

11.2.3 Data collection

The LCA practitioner should make the collection of primary data a priority. In many cases, however, this is not feasible. In such circumstances, the practitioner should use other data sources that meet the quality standards for databases as described in Section 10.3. In the absence of good quality data from databases, data shall be collected from other sources. In all cases, the source of the data and the quality of the source shall be well documented. The following sections provide guidance about which data requirements and sources for inputs should be used in the cultivation stage.

a) Seed plant material

Seed material often is taken from the previous crop or from a special seed crop. When products are harvested for their seeds, the crop yield can be different. Examples include wheat, rapeseed, and soybeans. Where the seed is not the intended crop product, it requires special production, as is the case with sugar beet. Seed materials are often treated against insects and fungi and should be stored properly for optimal emergence in the next growing season. These extra treatments require additional inputs, mainly of energy and pesticides. There is a wide variation in the use of energy and pesticides for seed.

Activity data collection: Data shall be collected with regard to:

- the amount of seeds or plant material used, expressed as kg per hectare; and
- the emissions per kg of seed from cultivation and regarding the additional energy, pesticides and transport inputs.

LCI data of production or estimation of LCI data*:* When seed is taken from a previous crop and requires little additional treatment, the most simple way to implement the LCI data is to reduce the crop yield by the seed amount. In all other cases, the total emissions per kg of seed shall be calculated by multiplying the additional inputs by the LCI data for cultivation, treatment and transport.

Databases provide emissions for total emissions per kg of seed, including all extra inputs (Table 4).

b) Manure application

Activity data collection: Data on the application of manure and on the degree of nitrogen and phosphorus provided by the manure shall be collected. This implies that data on the nitrogen and phosphorus content of the manure (kg/ton or m3) and the application rate of manure (m3 or ton /ha) shall be collected. When primary data are not known, secondary data shall be developed from regional or national statistics on animal numbers and from IPCC (2006) on nitrogen excretion. Data on phosphorus excretion are not (yet) available in any databases. Another option is to work with an N to P ratio, although this is highly variable around the world. In this situation, the most appropriate method is to calculate P excretion by assessing intake and retention in milk, eggs, etc.

Data on the method of manure application should be collected if this is required by the applied models used for calculation of N emissions.

***Emission models and LCI data**:* Depending on the emission models outlined in the goal and scope of the study, additional data may need to be collected as input parameters. If no specific model is available or required to quantify N_2O, NH_3 and NO_x emissions, then IPPC (2006), Volume 4, Chapter 11 should be used. Most LCA impact models can deal with phosphorus on agricultural land as an input factor. The included fate model translates this input into an eutrophication score. When the fate (leaching) is modelled even more precisely, emissions into water should be the input used for the eutrophication score, instead of the fertilizer input to land.

c) Nitrogen (N) from synthetic fertilizer

***Activity data collection**:* Data shall be collected on the application rate of synthetic nitrogen fertilizer, expressed as kg N per hectare..

***Emission models and LCI data**:* Depending on the selected emission models in the goal and scope of the study, additional data may need to be collected as input parameters. If no specific model is available or required to model N_2O, NH_3 and NO_x emissions, IPPC (2006), Volume 4, Chapter 11 should be used. LCI data for production can be obtained from suppliers if available or can be collected from secondary databases (Table 4 on data sources). If data from suppliers is used, a consistency check with secondary databases is recommended.

d) Phosphorus (P) and Potassium (K) from synthetic fertilizer

***Activity data collection**:* Data shall be collected on the application rate of synthetic phosphorus and potassium fertilizer, expressed as kg P_2O_5 or K2O per hectare, per type of fertilizer.

***Emission models and LCI data**:* Depending on the selected emission models in the goal and scope of the study, additional data need to be collected as input parameters. LCI data for production can be obtained from suppliers if available or can be collected from secondary databases (Table 4 on data sources). If data from suppliers is used, a consistency check with secondary databases is recommended.

e) Application of lime

***Activity data collection**:* Data shall be collected on the application rate of lime, expressed as kg CaCO3 per hectare. Lime often is not applied on an annual basis, but only occasionally or once in a number of years. The application rate of lime shall be averaged out over the years between two consecutive applications.

***Emission models and LCI data**:*The application of lime is of special importance for climate change because CO_2 is released after the application of lime. If the CaCO3 is from fossil origin, 1 kg application of CaCO3 yields 0.48 kg of CO_2. Liming can also take place with residual products (e.g. residues from sugar beet processing) from industry. These sometimes contain biogenic carbon which shall not be counted as a contribution to climate change.

Emission factors for CO_2 emissions from lime application shall be taken from IPCC (2006), Volume 4, Chapter 11. LCI data for production can be obtained from suppliers if available or can be collected from secondary databases (Table 4 on data sources). If data from suppliers is used, a consistency check with secondary databases is recommended.

f) Application of peat

Activity data collection: Data shall be collected on the application rate of peat, expressed as kg per hectare. Additional, data on the C/N ratio of peat shall be collected. If information on the chemical analysis of the product is unavailable, the content shall be assessed from internationally accepted databases. Peat is used to improve soil organic matter and soil structure and often is not applied on an annual basis, but only occasionally or once in a number of years. The application rate of peat shall be averaged out over the years between two consecutive applications.

Emission models and LCI data: Emissions from application of peat are of importance for climate change (CO_2 and N_2O). Both are released during the decomposition of peat. Emission factors for CO_2 and N_2O emissions from peat application shall be taken from IPCC (2006), Volume 4, Chapter 11. The production of peat requires only small amounts of energy. Information about the production process preferably should be collected from suppliers/producers, but reviewing the literature can help in the data collection process and by filling in gaps.

g) Application of pesticides

Activity data collection: Data shall be collected on the application rate of pesticides, expressed as kg active ingredient per hectare. Pesticides include herbicides, insecticides, nematicides and fungicides. Often the application rates are low and a breakdown by the various pesticides is not useful. Only when high rates of a specific pesticide are applied, shall detailed information be amassed.

Emission models and LCI data: The application of pesticides is important for climate change (CO2). However, due to the low energy requirements and application rates, emission rates will be relatively low.,. The most important impact of pesticides will be on ecotoxicity and biodiversity. These impacts are not included in the current guidelines.

h) Fossil fuel use

Fossil fuels are used directly for cultivation by tractors and self-propelling machines, for drying crops and for transport of products from the field to the farm or a processing plant. Fossil fuels are also used indirectly in the production of other inputs, such as fertilizers. The most common fossil fuels in agriculture are diesel for tractors and other machines and natural gas and heavy fuel oil. In addition, fuels such as coal and peat can be used. Emissions arise primarily from combustion of any of these fuels. In addition to the combustion emissions, other emissions occur due to the production and transportation of these types of fuels, from the production of capital goods and from the production and operation of the distributing grid. Contributions of upstream emissions can vary from 5 percent to almost 40 percent of emissions produced from combustion alone (Blonk *et al.*, 2010).

Activity data collection: Data shall be collected regarding direct fuel use, the amount used in the process per type of fuel and on the its sulphur content In the absence of primary data, secondary data on average fuel use per activity per hour and the on the hours of work shall be pulled together ed from internationally accepted databases.

Emission models and LCI data: Emission factors for both the combustion and upstream processes shall be taken from internationally accepted databases.

i) Machine use

When machines are used, the total fuel consumption should be calculated. In the absence of detailed data on fuel consumption, or in situations where part of the work is done by contractors, an alternative is to collect data on work time per machine (including the tractor). Data collection regarding machine use is also required for calculation of the emissions that are related to production and maintenance.

Activity data collection: Data shall be collected on the hours worked per machine, on the type of the machine and (if used) on the power of the tractor to drive the machine.

For all tractors and machines the weight and lifespan should be assessed. These data are difficult to come by and are important only in situations of high level of mechanisation. Databases can provide average figures for weight and lifespan (Table 4).

Emission models and LCI data: When data on fuel consumption are lacking, data on mean fuel consumption for tractors and self-propelling machines can be drawn from databases (Table 4). Emission factors for fuels have been described in the "*Section on* "*fossil fuel use*".

Emission factors for production and maintenance of machines and tractors are related to the weight and type of machine and tractor and should be collected from databases.

j) Electricity

Direct and indirect energy are often used in the form of electricity. Electricity is generated by using fossil energy sources and other types of energy sources, such as nuclear power, hydropower, biomass, wind or solar power. The mix of energy sources for electricity production is different for each electricity grid. Furthermore, the efficiency of converting fossil energy to electricity varies depending on the type of technology used. Electricity can also be produced locally, using the same energy sources..

***Activity data collection**:* Data shall be collected on the basis of the total amount of electricity used, expressed as kwh, and on the fraction taken from the grid and the fraction produced locally. In the case of locally produced electricity, the energy source shall be clearly documented.

***Emission models and LCI data**:*

Electricity taken from the grid: The country specific energy mix and the related combustion emissions should be taken from the International Energy Agency (IEA) database. The upstream emissions for the production of the fuels present in the country's mix shall be taken from an internationally accepted database. It also should be noted that the IEA data also include the emissions from the production of heat,, which likely leads to a decrease in totals.

Locally produced electricity: Emission factors for fossil fuels, biomass, water, wind- and solar power shall be taken from an internationally accepted database that takes into account all upstream emissions.

k) Crop residues

Crop residues are important for various reasons. First, in many regions the crop residue is harvested and serves as an important source of animal feed, as bedding material or as a resource for biofuel production. Second, the crop residues can make an important contribution of carbon and nitrogen to the soil, contributing to the organic matter balance of the field. Third, the nitrogen from crop residues that remains in the field causes emissions to be released into air and ground- and surface water. And,; lastly, combustion leads to emissions of nitrous oxide, nitrogen oxides (NOx), and methane. Emissions of crop residues produced by the field for other purposes, such as feed, biofuels, bedding etc. shall not be reported in this section.

***Activity data collection**:* Data shall be collected on the amount of above-and below-ground crop residues and the nitrogen content of both types of crop residues in order to calculate the total residual N per hectare. In most cases, primary field data are not available and default data or formulas to calculate crop residues shall be used. Nationally derived formulas or default data are to be preferred. If these are not available, the IPCC (2006) default formulas for crop residues shall be used.

When part of an above-ground crop residue is removed from the field, the following shall be documented:

- the amount leaving the field expressed as kg of product per hectare; and
- the purpose for which the removed residue is to be used.

***Emission models and LCI data**:*

Crop residues without burning: As per the IPCC (2006, Volume 4, Chapter 11), direct and indirect emission factors for nitrous oxide shall be used, unless specific national emission factors are available.

Crop residues burnt in the field or elsewhere: CO_2 emissions from burning are not to be taken into account, as they belongs to the short carbon cycle. Emission factors for methane, nitrous oxide and nitrogen oxides shall be based on IPCC (2006), Chapter 2, Volume 5, unless specific national emission factors are available.

l) Land use type and management

Soil organic matter contents often change as a consequence of land management. Soil organic matter is accumulated under grasslands where the accumulation rate depends on factors such as climate, soil type and age of the grassland. When it comes to arable land, soil organic matter is decomposed at relatively high rates and extra inputs are often required to keep the soil organic matter at acceptable levels. CO_2 emissions from soil organic matter are known to contribute to climate change. However, changes in management can lead to changes in soil organic matter. In other words, the adoption of different soil tilling practices on existing cropland or shifting from extensive pastures to intensive managed grasslands can cause significant changes.

A specific situation of land use management is the cultivation of paddy rice. Intermittent or permanent flooding will result in methane emissions.

The IPCC defines 6 land use categories:

- forest land
- cropland
- grassland
- wetlands
- settlements
- other land

In the case of feed production, grassland, cropland and forest land are of extreme importance. Staying within one land use category gradually will affect below- and above-ground biomass. In forests and grasslands, organic matter will accumulate, albeit slowly in the case of arable land a slow decrease will take place.

The accumulation of organic matter in grassland is often referred to as carbon sequestration. The sequestration rate in grassland depends on the age of the grassland, the level of nutrient inputs¸ the type of use (grazing or cutting), the soil type, the current level of soil organic matter and the agro ecological zone (temperature and precipitation).

Carbon sequestration in forestland depends on the type of forest, the age of the forest, the current amount of above- and below-ground biomass and the removal of biomass via browsing, harvesting leaves or cutting- The agro ecological zone (temperature and precipitation) also plays a key role.

The decrease rate on arable land depends on the actual organic matter content of the soil, the crop rotation, additions of organic matter via green manure or animal manure, the amount and removal of crop residues and the agro ecological zone (temperature and precipitation).

Activity data collection: Data shall be collected on land use type and on the soil tillage management. Additionally, data should be collected on the actual soil organic matter content.

Emission models and LCI data*:* Calculation of soil carbon dynamics is complex, time-consuming and requires large amounts of data. One simple approach does not exist. The lack of a uniform approach explains why TS 14067 and PAS 2050 state that land use emissions do not need to be calculated. In developing these guidelines, it was however decided that GHG emissions (and removals) related to land use shall be included in the assessment. This is because these emissions (or removals) can be of great importance in certain system and could thus not be neglected.

A set of criteria for the calculation of changes in soil carbon stocks therefore shall be applied:

- Changes in soil organic matter content in arable land and grassland shall be based on calculation models using primary data of long term measurements. Such models are available in literature. When primary data is lacking, models can be calibrated on the basis of default carbon stocks defined by IPCC (2006), Volume 2, Chapter 2: generic methodologies applicable to multiple land-use categories.
- The soil carbon models used in the assessment shall be published in peer reviewed scientific papers and have received good acceptance.
- Models should take into account the agro-ecological zone, soil type and previous land use history.
- If no national or regional models are available, data can be taken from the Appendix on Land Use Emissions", which is valid for western European/temperate conditions.

- Land use emissions shall be reported separately.

m) Land use type and management: paddy rice

Methane is emitted during the cultivation of paddy rice.

Activity data collection*:* Data shall be collected on:

- the length of the period from seeding to harvest. In the case of ratoon rice, the first period from seed to seedlings shall be taken into account;
- the water regime during cultivation;
- the water regime in the pre-cultivation period; and
- modifications of soil organic matter.

Guidance on data requirements can be found in the 2006 IPCC Guidelines.

Emission factors: The methodology used to calculate methane emissions from rice cultivation should be that in the 2006 IPCC Guidelines (IPCC, 2006).

n) Soil type

Organic soils will decay when they are drained and used for agriculture. The groundwater level is lowered by drainage, causing air (and oxygen) to enter the soil profile and reduce the organic material, much of which is oxidized. The rate of shrinking and oxidation depends on the drainage level and partly on the type of organic soil. Oxidation results in the release of plant nutrients, which will affect plant production. The release of extra nutrients from peat decomposition can contribute significantly to crop production. However, in this case they shall not be treated as an input, because emissions related to the release of nitrogen are already assessed in the decomposition of peat. Changes in soil organic matter in mineral soils are covered in the section on land use.

Activity data collection: Information on soil types shall be collected. In the case of organic soils, data on the type of organic soil and on groundwater levels shall be assembled.

Emission factors: Emission rates per unit of area per year for organic soils with different groundwater levels can be taken from databases. Further documentation is provided in the Annex on peat oxidation..

o) Land-use change (LUC)

Land-use change occurs when land shifts from one land-use category to another. In the case of feed production these may include:

- change of forest land to grassland, arable land or perennial land;
- change of grassland to arable land or perennial land;
- change of arable land to grassland or perennial land; and
- change of perennial land to arable land or grassland.

Land-use change is related to a range of economic, institutional and environmental factors. One of the complicating factors in calculating CO_2[10] emissions from land-use change is the need to distinguish between direct and indirect land-use change. Another is the controversy regarding the drivers of land-use change, related to the many processes and stakeholder involved. A further issue is the lack of data and consistent time series in particular. These elements pose substantial problems to the modeller, both in computing emissions and in attributing hem to the drivers of land-use change. Many different approaches exist, all relying on strong assumptions regarding direct and indirect land-use change and their respective drivers. Thus, so far, no widely accepted method has been developed. The only

[10] Land-use change causes multiple GHG emissions (CO_2, CH_4 and N_2O) depending on the method of change. For example if a forest is burned, methane and nitrous emissions also occur. The same goes for conversion of grassland to arable land which releases both CO_2 and N_2O. In the tools provided for these calculations, such emissions are converted to CO_2-equivalents.

consensus is that land-use change emissions should be reported separately (e.g. TS 14067 and PAS2050).

Recognising the ongoing debate and need for further methodological development, these guidelines recommend estimating land-use change using the ENVIFOOD method adapting the PAS2050-1 2012. This approach gives particular emphasis to local considerations and the user shall compare results with another method developed by Audsley et al. (2009) and Vellinga et al. [2013], which is globally orientated. The comparative analysis shall be done for feed material other than grass from natural rangelands[11], since the feed products from these lands would not enter in the global market.

The ENVIFOOD/PAS2050 method identifies three different situations:

1. **When the country of production and the previous land use is known.**

When the exact origin of a product is known and the previous land use is known, then LUC shall be directly calculated. Data shall be collected on previous land use, on the carbon stocks in the previous and current land-use categories in the agro-ecological zone and, if relevant, the forest type. Where primary data is available, such data shall be used. PAS2050-1 2012 provides further guidance on this. When primary data on carbon stocks are not available, the IPCC provides default data for carbon stocks and related emissions.

2. **When the country of cultivation is known but previous land use is unknown.**

When there is limited information regarding the specific location from which the product or product components are extracted or harvested, it can be difficult to determine how to attribute or distribute impacts. When the exact origin of a product is unknown, but the country of cultivation is known, the calculation shall be based on the PAS 2050-1 (BSI, 2012), as slightly modifies in Food SCP RT (2013) and can be summarised into a four step approach:

- has cropland expanded in the country?
- if so, has the crop under assessment expanded?
- if so, how much, respectively, into grassland and into forest land? And finally
- how much of forest and grassland LUC can be attributed to each crop in the process of expansion?

In countries where forest and grassland are not declining, no land-use change emissions are calculated. Land-use change emissions from forest and grassland decrease are proportionally allocated to the increasing crops on the basis of their area increase. Subsequently, the emissions per crop are partitioned over the total national yield from all hectares of the specific crop. An Excel tool has been developed to support the estimates of LUC emissions based on the PAS2050-1/ENVIFOOD protocol

[11] uncultivated land on which the native vegetation is predominantly grasses, grass-like plants, forbs or shrubs suitable for grazing or browsing use, primarily managed through the manipulation of grazing (Kothman 1974, NRCS 1997, Eagle et al. 2011).

approach (Currently available at www.blonkconsultants.nl). This tool has been reviewed and approved by WRI.

3. **When the country of cultivation is unknown**

When the country of cultivation is unknown, the GHG emissions arising from land-use change shall be calculated on the basis of the weighted average of the average land use change emissions of that commodity in the countries where it is grown (cf. above for the calculation in each of the producing countries).

The global average method

The method is based on the concept that all agricultural production systems are connected and that therefore it is the sum of all agricultural production that drives land-use change Audsley et al. (2009) and Vellinga et al. (2013). This is especially the case for market-oriented agriculture commodity production, to a lesser extent to non-commercial agriculture and would not apply to products from natural vegetation. In this approach, all land-use change emissions (non-agricultural land converted to agricultural land) are related to all agricultural production. All areas in agriculture production are thus attributed a unique global average emission from land use change, computed as follows:

Average GHG emissions = total GHG emissions from land use change / total global agricultural land use (excluding rangelands)

Global GHG emissions from land use change have been assessed at 5.77 Gigatons, total global land use is 4.89 billion hectares (FAOstat, 2013), of which 0.47 billion hectares is rangeland (Henderson et al., forthcoming).

The average land use change emissions are:

$$5.77 / (4.89 - 0.47) = 1305 \text{ kg } CO_2 \text{ eq. per hectare.}$$

p) Data inventory of crop yields

Crop yields can be classified into the following categories:

- one crop per year, one product, no co-products;
- one crop per year, multiple co-products;
- multiple subsequent harvests per year of one crop, no co products;
- multiple crops per year, not necessarily of the same crop; and
- a mix of crops that are harvested once per year with crops harvested multiple times per year.

Activity data collection: Data shall be collected concerning the net yield of all the products or co-products per hectare. The net yield is the amount of product in kg per hectare leaving the field. If primary data are not available, default data shall be used from databases and statistics. Data shall be collected over at least three consecutive years to average out annual variations.

When crops are sold, care should be taken to note the amount sold since because of storage losses or due to the presence of a poor quality fraction that is remains unsold, this can differ from the net yield. When the amount sold is lower, due to losses, total emissions shall be divided by the (lower) net yield; when the sold amount is lower due to an unsold fraction, emissions shall be allocated to both fractions.

In the case of multiple crops per unit of land, as in alley cropping or co-products as wheat and straw, or in the case of multiple crops per year, data shall not be aggregated but be collected and stored at the highest level of detail, i.e. per single co-product. Depending on goal and scope, one option is to combine multiple harvests per year of single crops as is the case with grass or alfalfa, to one total annual harvest. The advantage is simplicity and easier data collection; the disadvantage is that seasonal variation in feed quality is not taken into account.

When primary or secondary data are collected, information shall be amassed about the used land area. When crop yields are expressed per unit of land, the gross area shall be used as a reference point so that unutilized parts, internal ditches, waterways and internal infrastructure are also considered. The difference between net land and gross land occupation can range from 5 percent to 25 percent. When fallow land is an essential part of the production system, it shall be incorporated into the calculation.

GROSS AND NET AREA OF AGRICULTURAL LAND

Cultivation of crops requires more land than just the area where the crop grows. Internal roads, internal small waterways, ditches, mandatory fallow strips and other areas are essential for cultivation but do not themselves produce crops. The difference between net land and gross land occupation can range from 5 percent to 25 percent. If part of the farm is untouched nature land (as is mandatory in some countries), this should not be incorporated into the gross land area.

In very arid regions, holding land fallow every second year, with a crop is grown in the years in between, is a practice designed to save water. Both years are essential for the production of the crop and should be incorporated into the calculation of the land occupation.

11.2.4 ATTRIBUTING EMISSIONS AND RESOURCE USE (OR ACTIVITIES AND INPUTS) TO SINGLE PRODUCTION UNITS

In the previous section, all inputs, resources and emissions were identified and quantified, and the guidance on how and what kind of data and emission factors to collect was provided. These inputs and emissions then need to be classified into:

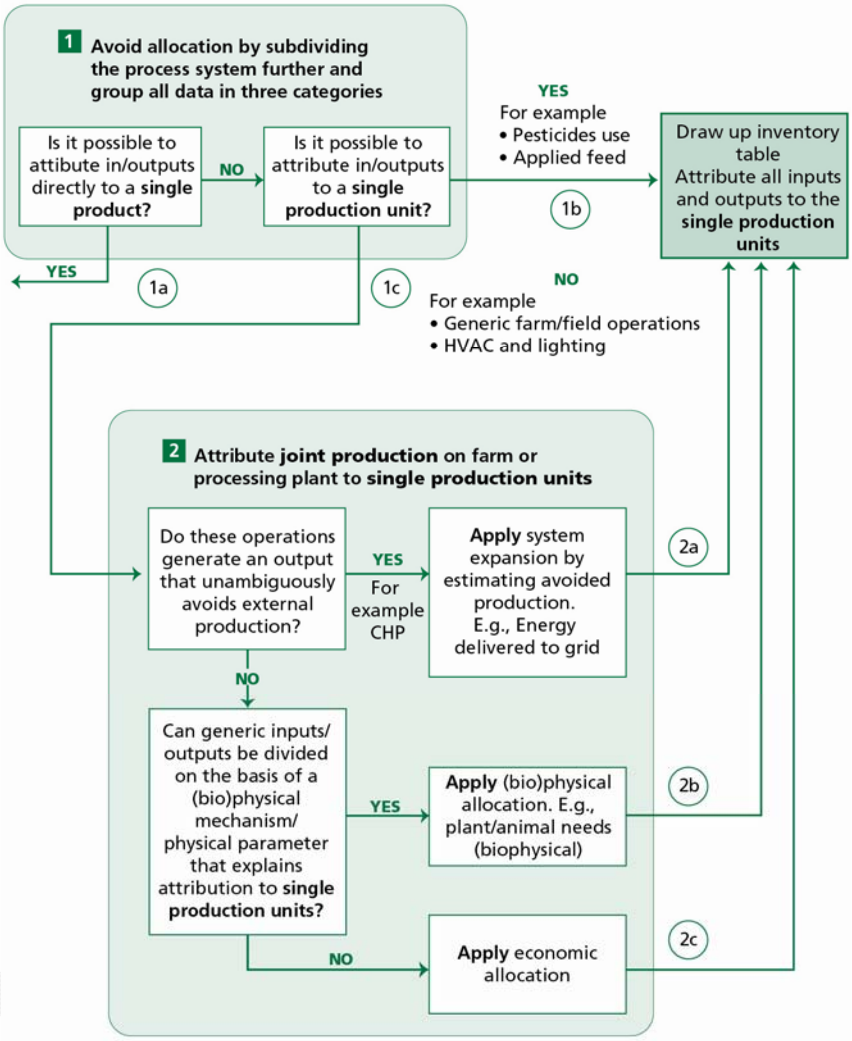
1. *Generic inputs and emissions at farm level*: These cover more than one field at a farm and more than one production cycle. An example is investment in irrigation infrastructure on a dry part of the farm. This has to be attributed to the dry part only, and for the longevity of the infrastructure.
2. *Generic inputs and emissions at field level*: These are inputs that cover more than one production cycle, but are field oriented. These inputs only need an attribution in time, to the single production cycle. An example is the slow release of nutrients from manure in crop rotation, such as the organic nitrogen fraction, phosphorus, the application of lime and the growth of green manure to increase the soil organic matter content. They would also include annual activities that benefit multiple harvests of a perennial crop.
3. *Field and production cycle specific inputs and emissions*: These involve the production unit: one specific field and one production cycle. These inputs still can cover more than (co-) product from the field. Examples include the application of synthetic nitrogen fertilizer or the harvesting of wheat with a combined harvester, a process that produces both wheat and straw. The wheat is collected and the straw is left in the field.
4. *Field, production cycle and co-product specific inputs and emissions*: This is a more specific application than the previous one, covering inputs that are specifically meant for one co-product. An example is the baling of straw after the wheat grains have been harvested.

Applying the left hand part of the allocation scheme (Figure 12) will bring together all inputs to the same unit of production: the field with its production cycle. The design of the allocation scheme can be read as follows.

- **Category 1** (in Box 1, Figure 12): If inputs cannot be attributed to a single product, as they cover multiple fields and years, and cannot be attributed to a single production unit, line **1c** has to be used, leading to Box 2, Figure 12, "*The inputs do not unambiguously avoid external production*". The next question is whether physical mechanisms can be applied. In many cases there is a relevant physical relationship and if so, line **2b** is used and the product can be attributed to the single production unit.
- **Category 2**: This is almost identical to **Category 1** above, except that inputs cannot be attributed to one single product. They only cover one field, but they involve more than one year. This leads to the same results, going along lines **1c** and **2b**.
- **Category 3**: This applies if in Box 1, Figure 12, the inputs cannot be attributed to a single product, but can be attributed to a single production unit and line. In this case, **1b** is used.
- **Category 4**: If inputs can be attributed to a single (co-) product, line **1a** is used[12].

[12] This line is cut off in Figure 12. It immediately leads to the right hand side of the allocation scheme (see complete allocation scheme, Figure 7).

FIGURE 12: ALLOCATION OF ALL INPUTS TO THE SINGLE PRODUCTION UNIT



Note: The chart above represents the left-hand side of Figure 7.

Perennial crops are a good examples of a situation in which a combination of generic inputs at field level and specific inputs occur simultaneously. Moreover, a perennial crop has a production cycle lasting several years. The first years of the production cycle, the crop is in a juvenile stage and production is still low, after this there is a period of maximum production, followed by declining production in the last years. A steady state situation, assuming that all production stages and generic inputs are proportionally represented, can be used to assess all inputs and outputs. In that case, the inputs can be considered as attributable to one production unit and line **1b** can be used.

An almost similar situation is seen in crop rotations where inputs can be transferred from one crop to another or, e.g. where green manure grown every two years produces beneficial effects for the complete crop rotation. These inputs cannot be attributed to the single production unit immediately. But the application of allocation via line **2b** can be done in a simplified way, by averaging out inputs over all fields in the rotation and ignoring all complex physical relationships regarding the transfer of inputs from one year to another.

When in crop rotations or in perennial crops, a steady state situation is not present, then corrections have to be made.

At the end, all inputs, resource use and emissions can (at least partly) be attributed to the unit of production by using the following formula:

$$(E,R)_{TotField,Cycle} = \sum(E,R)_{Farm,Period} \times alf_{Farm,Period} + \sum(E,R)_{Field,Period} \times alf_{Field,Period} + \sum(E,R)_{Field,Cycle}$$ *(formula cultivation 1)*

In which:

$(E,R)_{TotField,Cycle}$	=	total emissions and resource use of the production unit for cultivation per production cycle (single or multiple harvest in a growing season)
$(E,R)_{Farm,Period}$	=	emissions and resource use of generic farm activities for a period of multiple production cycles for cultivation
$Alf_{(Farm,Period)}$	=	allocation factor for emissions and resource use of generic farm activities for a period of multiple production cycles for cultivation
$(E,R)_{Field,Period}$	=	emissions and resource use of generic field activities for a period of multiple production cycles for cultivation
$Alf_{(Field,Period)}$	=	allocation factor for emissions and resource use of generic field activities for a period of multiple production cycles for cultivation
$(E,R)_{Field,Cycle}$	=	emissions and resource use of specific field activities for one production cycle for cultivation

Each part of the formula with (E,R) can be broken down to:

$$(E,R)_{a,b} = (E,R)_{direct,a,b} + (E,R)_{indirect,a,b}$$ *(formula cultivation 2)*

In which:

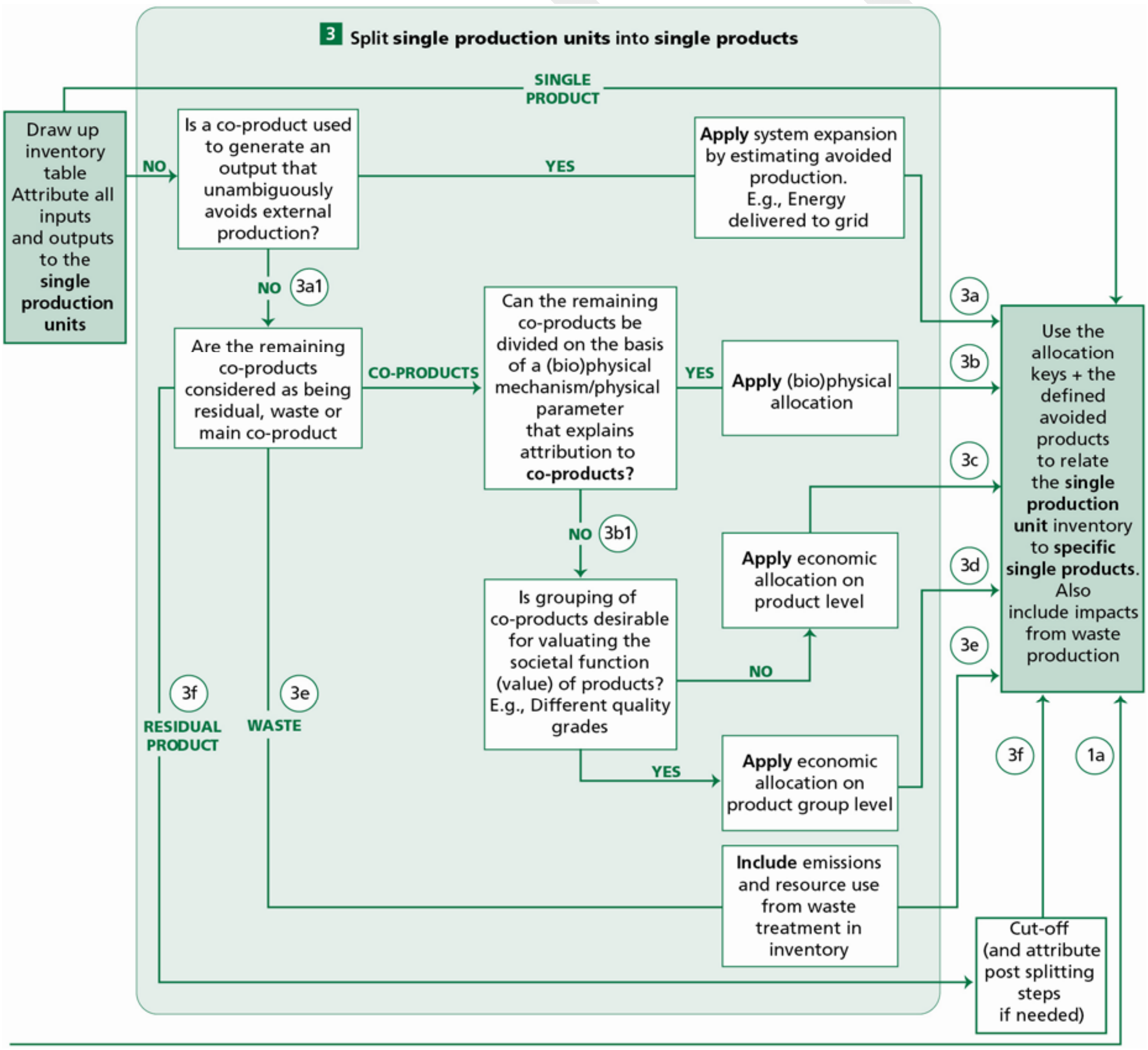
(E,R) a,b	=	total emissions and resource use of **a** and **b** for cultivation, where **a** can be farm and field level and **b** can be for a certain period or a production cycle.
(E,R) direct, a,b	=	direct emissions and resource use of **a** and **b** for cultivation, related to the use of the inputs (as e.g. fuel combustion)

(E,R) indirect, a,b = indirect emissions and resource use of a and b for cultivation, related to the upstream production of the inputs (as e.g. the upstream emissions to produce the fuel)

11.2.5 ATTRIBUTING EMISSIONS AND RESOURCE USE TO (CO-)PRODUCTS (ALLOCATION)

In the previous section, all emissions from inputs and resource use have been attributed to the basic production unit. In crop cultivation, more co-products per crop and more crops per production unit can be generated. This means that the $(E,R)_{TotField,Cycle}$ has to be attributed to the different co-products or crops. The allocation principles represented in Figure 13 can be applied in a number of situations.

FIGURE 13: ATTRIBUTION TO (CO)-PRODUCTS, CULTIVATION



Note: The chart above represents the right-hand side of Figure 7.

Situation 1 with only a single product: This is a simple situation and the line “single product” at the top side of the scheme can be used.

Situation 2 with multiple co products e.g. millet and stover: The scheme will be applied for stover where stover is used as animal feed which leads us to Box 3, Figure 13. Stover does not unambiguously avoid external production when it is used, because it replaces the need for other feed. Line **3a1** (Figure 13) can be used. The stover is not considered as a waste or residue, which means that it has to be considered as a co-product. The subsequent question is whether physical allocation can be applied or not. In this case, where the stover is used as feed, physical allocation can be applied, by allocating on the basis of the digestible energy of both the millet and the stover, as has been applied in the GLEAM model (Gerber *et al.*, 2013). This means that line **3b** (Figure 13) can be used.

Situation 3 with multiple subsequent harvests of one crop and zero co-products: An example is multiple cuts of grass that are grazed or cut for hay or silage. When the yield of a single cut is the reference unit, the rules of situation 1 can be applied. The LCA practitioner should be aware that the unit of production is the single cut per field and attribution of emissions to the production unit requires special attention. Additionally, land occupation, land use and land use change require special attention as these are based on a production cycle of one year and not on a fraction of the year.

Situation 4: the double-cropping systems with soy and maize as sequential crops grown on the same field is a good example. In this case, the unit of production is the field per half a year and this requires attention in attributing emissions to the production unit, especially when they stem from land occupation, land use and land-use change, as was the case with situation 3.

Situation 5: A good example here is the alley cropping system, where three different crops grow in the same field, all with different planting and harvesting schemes. Entering the right hand side of the allocation scheme (Figure 13), system expansion cannot be applied. In the next step, however, a physical allocation is a useful option. The allocation can be based on crop requirements, on the transfer of nutrients and also on the positive effects of the system. Such an allocation however requires very detailed information. The application of a simple area-based allocation might introduce some inaccuracy, but is much easier and faster to apply. See Box 4 on *push and pull system*.

Box 4: Push and pull of the stem borer

The push and pull technology is a strategy for controlling agricultural pests by using repellent "push" plants and trap "pull" plants. In a number of regions, the stem borer is a serious threat to crops. A combined production of maize, Desmodium and Napier grass has proven to be a successful push and pull system to control damage from the stem borer. Grasses such as Napier are planted around the perimeter of the crop to attract and trap the pests, whereas other plants, like Desmodium, are planted between the rows of maize to repel the pests and control the parasitic plant. In addition, Desmodium is a leguminous crop, fixating nitrogen and releasing this for the benefit of the maize crop.

The three crops have different production cycles, Napier is a perennial crop standing for 5 to 10 years, Desmodium is a bi-annual crop, while maize is a single annual crop. Napier and Desmodium are harvested multiple times per year as animal feed. On the other hand, maize is only harvested once a year, with the grain used for human consumption and the stover for animal feed. In addition, although Napier grass is a very productive crop, it does mines the soil of its nutrients during its growth period. Following the removal of the Napier and its replanting, high amounts of manure are usually applied to act as a nutrient reserve for multiple years.

These interactions can give rise to many complex allocation approaches where the benefits of Desmodium and Napier for the maize crop can be quantified. It is clear however, that the production of Desmodium is not negatively affected by the alley-cropping system.

The simplest way is to treat the crops as separate with their own area and their own nutrient requirements. This implies that the manure application at the replanting of Napier grass has to be attributed to the number of years in the production cycle of Napier and the same holds for planting. In the first year, the inorganic nitrogen can be attributed to that crop, while the other five years will benefit from the organic nitrogen from manure. Another option is to evenly partition the nutrients from manure over all six years.

For Desmodium, manure and planting requires attribution to two years, while in th case of maize all activities are annual. When Napier is replanted, all other crops having been removed from the field, and manure is applied at high rates over the entire field; this manure application for Desmodium and maize has to be treated separately from the others, as application rates might differ.

Finally, the emissions and resource use from maize cultivation must be attributed to the grain and stover. Since the stover is used for feed, allocation may be done on the basis of digestible energy content. In situations where the stover is used for other purposes, such as biofuel production, an economic allocation is recommended. Human food (the grain) and biofuel (stover) represent different goals and serve different markets and the energy content only is partly reflects the physical causality.

The general model for attributing inventory data per production unit to co-products is expressed by the cultivation formula 3.

$$(E,R)_{(co)-product} = \frac{\sum(E,R)_{Field,Cycle,(co)product'} + (E,R)_{TotField,Cycle} \times Alf_{(co)product}}{Y_{(co)-product}}$$

In which:

$(E,R)_{),(co)-product}$ = emissions and resource use per kg of (co)product

$(E,R)_{Field,Cycle,(co)-product}$ emissions and resource use directly used for the (co)product per production unit for cultivation

$(E,R)_{TotField,Cycle}$ total emissions and resource use of the production unit for cultivation

$Alf_{(co)-product}$ allocation factor for emissions and resource use of the fraction of the emissions to be attributed to the (co)-product for cultivation

$Y_{(co-)product}$ the net yield of the (co-)product

How to calculate the allocation factors?

The allocation factors can be calculated on the basis of the net yields of all (co)-products and their characteristics, such as gross energy, mass or price.

$$Alf_1 = \frac{Y_1 \times w_1}{\sum_1^n Y_n \times w_n}$$

In which:

Alf 1 = the allocation factor for (co)-product 1

Y_n = the net yield of (co)-product **n**

W_n = the weight factor of (co)-product **n**. The weight factor can be the gross energy, the price and the mass, but other criteria also can be used. In case of mass, all values for **w** are set at 1.

The mass based allocation should be performed on the basis of the total dry matter sum of the outputs. The mass based allocation on a dry matter basis is also the starting point for applying a gross energy content-based allocation. Per co-product the caloric value is determined on the basis of the Low Heating Value (LHV) of the chemical components (default caloric values per group: fat/oil =37 MJ/kg, protein = 24 MJ/kg, carbohydrates = 18 MJ/kg, water = 0 MJ/kg and not negative. In the case of economic allocation, it is not necessary to consider the dry matter balance of the process, because prices for the most part are linked to the co-product as it is. It is a good check, however, in the inventory stage of the LCA. In the sensitivity assessment, the same definition of “co-products considered as residues” should be applied.

11.2.6 Wild caught fish

Catching wild fish can also be considered as a form of cultivation: the inputs can be assessed in the same way and the output is the caught fish. The main input in fishing is the energy use for the fishing vessels, used for combustion in the diesel engine and for generators for cooling equipment (Figure 14). In studies it is usual to express the amount of diesel use per ton of fish landed. There is a wide variation in energy use among fishing vessels. The use of cooling agents can cause emissions contributing to climate change. Modern fishing vessels apply cooling agents that don't contribute to climate change. Similar to machine use in cultivation, the emissions of production and maintenance of vessels should be incorporated In attribution. An important aspect of wild caught fish is the potential depletion of fish stocks. These effects are not part of these guidelines. Figure 14 defines the data and the emission factors that have to be collected

Figure 14: Inventory flow chart for fishing

PRIMARY ACTIVITY DATA AND EMISSION MODEL PARAMETERS	EMISSION FACTORS
Fuel use (litres per hectare, fuel type)	• If data no quality data on emissions and resource use is available *see, Table 4, Section 10.2.2* for guidance on secondary data
Machine use (hours, type)	• Per machine type: average fuel consumption/hour • Production and maintenance: If data no quality data on emissions and resource use is available, *see Table 4, Section 10.2.2* for guidance on secondary data
Refrigerants (kg, type)	• Per machine type: average fuel consumption/hour • If data no quality data on emissions and resource use is available, *see Table 4, Section 10.2.2* for guidance on secondary data
Fish yields (kg, co-products)	• Assess main and by-catch • If data no quality data is available in relation to fuels, machines and refrigerants, *see Table 4, Section 10.2.2* for guidance on secondary data

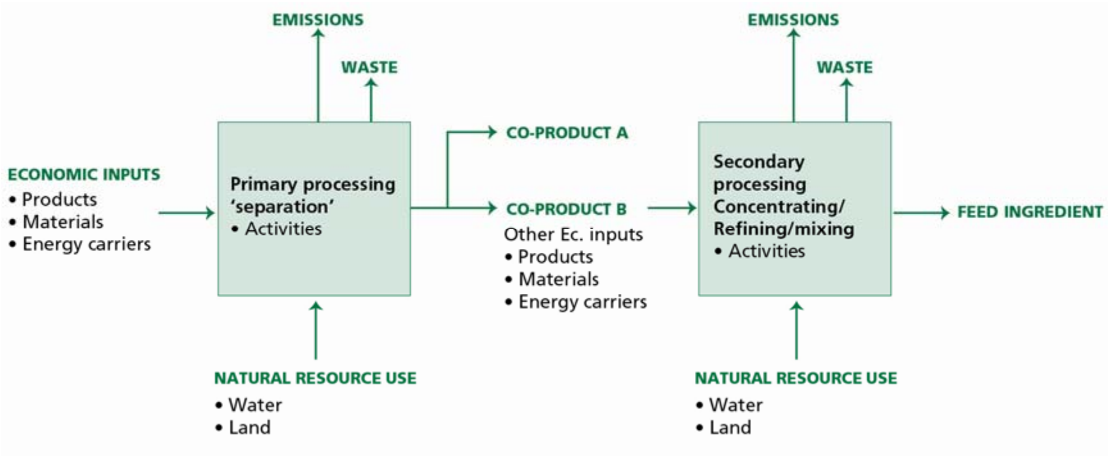
For relevant data collection, emission models and LCI data for fuel use and machine use refer to the sections in the cultivation section. For refrigerants, data shall be collected according to the type and loss of refrigerants. Emission factors or LCI data can be obtained from databases.

11.3 Gate-to-gate assessment of the processing of feed raw materials

11.3.1 Description of the processing system

Generally, the processing stage of a feed raw material consists of multiple steps (Figure 15). First, the plant or animal raw material is divided into several components. For example, soybeans may be split into soybean meal and crude soybean oil or sugar beet into sugar, wet beet pulp and molasses. Often, these products are further processed to constitute a dry, tradable feed ingredient. These processes may include purification and concentration of the feed ingredients. Products can also be further processed to increase digestibility or may involve further mixing with other raw materials either originating from the same process (e.g. adding soybean hulls to soybean meal or adding molasses to the pulp) or external processes.

FIGURE 15: EMISSIONS FROM AND RESOURCE USE IN PROCESSING FEED RAW MATERIALS



Not all steps in the processing sequence are included in the calculation. Co-products that are considered to be residues (see glossary for definition), become relevant for the LCA at the point in which they appear in the process. according to the recommended allocation principles in these guidelines.

Processing inventory tables should be derived from an assessment that models the average operation. This can best be derived by using mass flow balances of the most recent three years to average out abnormalities due to accidents, refurbishing or changes in equipment. By averaging over a three-year period, seasonal fluctuations, too, that may affect the energy efficiency of processes and fluctuations in production/ capacity ratio will likely be covered.

Upstream emissions and resource use of inputs at the processing stage can be separated into two groups. The first group includes all upstream emissions and resource use of the incoming feed raw material to be processed. These emissions shall be included and can be assessed on the basis of Section 11.2 on cultivation The second group of upstream emissions and resource use concern the total of upstream emissions of the other inputs at the processing stage, such as fuels and ancillary materials.

11.3.2 RELEVANT INPUTS, RESOURCE USE AND EMISSIONS DURING PROCESSING

Figure 16 defines the data and the emission factors that have to be collected.

FIGURE 16: THE INVENTORY FLOW CHART FOR PROCESSING

INVENTORY	EMISSION FACTORS
Input products (type)	All upstream emissions of products entering the processing unit • Plant origin: *see cultivation section 11.2* • Animal origin: *see LEAP Animal supply chain Guidelines* • Fish: from fishing process
Storage loss (kg, percentage)	• Correction of upstream emissions
Fuel use (litres, m3, kg, type)	• Per fuel type (CO_2, SO_x, NO_x, crude oil, MJ for all fuels) • Per unit of fuel
Electricity (kWh, type)	• From grid: IEA database for energy mix • Own production: fuel consumption • Per fuel type (CO_2, SO_x, NO_x, crude oil, MJ) from databases • Per unit of fuel from databases
Ancillary materials (kg, type)	• Per type of material: relevant emission factors from databases
Output products (kg, type, DM, price, GE)	• Not relevant
Define waste and residue products	• Not relevant
Waste treatment and storage	• CH_4 – emissions from anaerobic wastewater storage • CO_2 – energy use from wastewater treatment *See section 11.2.3 on fossil fuels*
Residual treatment and storage	• CO_2 – energy use for treatment. *See section 11.2.3 on fossil fuels*

a) Input products

The input products for the processing plant can be of plant origin, such as wheat, cassava and oilseeds, of animal origin, for example slaughter by-products and blood meal, and fish products. The input product is processed and split into a number of co-products, residues and waste. The energy and ancillary materials that are used to run the process and which are referred to as “inputs” in this guideline do not appear as outputs after processing in the processing scheme.

***Activity data collection**:* Data shall be collected on the type of input material (plant and animal) and on the chemical characteristics of the input product.

The reference flow in the processing plant is expressed per kg of product (or sometimes per 1000 kg of product), hence there is no need to collect information about the total amount of input product. However, when it is necessary to collect quantitative information about the partitioning into co-products, it may be useful to collect data on the amount of input and output products. This can then be normalized to a per kg value.

Emission models and LCI data: Input products of plant origin. The emissions from products of plant origin shall be collected on the basis of the description of the cultivation process (Section 11.2) or from suppliers. When primary data are lacking, data shall be taken from a database. Refer to Section 10.2.2 for guidance on criteria for collecting and using secondary data.

Input products of animal origin. In the case of livestock products, the emissions shall be collected on the basis of the description of the livestock systems. In the case of wild caught fish, the emissions shall be collected on the basis of the description of the process of catching wild-fish (Section 11.2).

b) Storage losses

If the input product is stored before processing, there can be losses due to dissimilation, decay, rodents, fungi etc. The upstream emissions of the input product shall be corrected for the losses.

Activity data collection: Data on the storage losses shall be collected for the period between reception at the production unit and the processing of the input product. When no primary data are available, secondary data on average storage losses shall be collected from internationally accepted databases.

Emission models and LCI data All upstream emissions shall be corrected for the losses during storage.

c) Fossil fuels

Ddata collection on fossil fuels and the emission factors are the same as those described in the cultivation section, sub-heading “fossil fuels”.

d) Electricity

Ddata collection on electricity and the emission factors are the same as those described in the cultivation section, sub-heading “electricity”.

e) Ancillary materials

Ancillary materials are chemicals that are used in processing. An example is the hexane that is used for extraction of oil from oilseeds. Part of the ancillary materials may be emitted to the atmosphere or to waste water. The emissions ancillary material shall be calculated.

Activity data collection: Data shall be collected on the ancillary material itself (chemical name, etc.) and on the amount of such materials consumed during the processing of input products. When no primary data are available, secondary data on the average consumption of ancillary material per activity or process shall be collected from internationally accepted databases.

Emission models and LCI data: Depending on the ancillary material, the relevant emission factors shall be collected.

f) Output products

At the processing plant, products are often split in two or more co-products; one problem is that if some co-products get additional treatment, part of the input product can evaporate.

Activity data collection: Data shall be collected about all output products and flows, irrespective of their status as co-product, waste or residues. The total of output products shall be the same as the total of the input product(s). Special attention shall be paid to other emissions during processing, e.g. hydrogen sulfide in the case of crushing rapeseed.

Additionally, for allocation purposes, data shall be collected per co-product and other flows on the dry matter content, the gross energy content and the price of the products.

The price of the products shall be based on the prices at the point of separation in the processing plant. In many cases, prices include transport costs, insurance, levies and other charges. In those cases, prices shall be corrected. When no primary data are available, secondary data on average gross energy or dry matter content per activity or process shall be taken from internationally accepted databases (Table 4).

Emission models and LCI data: Not relevant.

g) Definition of waste and residues

Part of the material flows will not be utilised further and therefore should be considered as waste materials. Other will be considered as residues.

WASTE IS NOT ALWAYS WASTE.

In Thailand, pineapple fruit is processed and canned into sliced pineapple, with the pineapple rind as a co-product. Initially, pineapple rind was considered a waste and was disposed off at landfills, a process that proved to be quite costly for the canning factory. Later, arable farmers were asked to allow disposal of the pineapple skin on their arable land, where it could be used as an organic amendment and as a fertilizer. At the outset, farmers were compensated for accepting pineapple skin which was used either as an organic amendment or as cattle feed to enhance productivity. However, this situation has changed; due to the high demand for the rinds as feed, the canning factory now sells the pineapple residue to farmers.

In Kenya, pineapple rind originally was used as animal feed. With the increase in fertilizer prices, pineapple plantations, linked to the canning factories, replaced synthetic fertilizer with pineapple rinds which proved more profitable than selling the pineapple as a feed.

Activity data collection: The list of output products shall be completed by identifying every output product explicitly as co-product, residue, or waste. Although formally this should be done after the second step of the allocation procedure where emissions of a single production unit are allocated to single co-products, the LCA practitioner apply the allocation scheme to identify the residue and waste products.

Emission models and LCI data: Discussed in subsequent sub-sections.

Waste treatment and storage*:* Storage of organic waste can cause emissions of methane, a potent greenhouse gas. Sometimes organic waste is processed in an anaerobic digester to produce biogas. Methane emissions can occur when biogas is used to produce heat, steam or for combined heat and power production caused by methane slip in the combustion equipment. Methane emissions can also occur due to storage of organic waste. For example, after processing of palm kernel fruit, the waste product (POME) is sometimes processed in an anaerobic digester applied to arable land but only after some time has passed.

Activity data collection: Data shall be collected on the amount of waste stored, the period of storage, the average ambient temperature during storage. When no primary data are available, secondary data on average emissions per activity or process shall be collected from internationally accepted databases.

Emission models and LCI data: The methane emission factor shall be derived from National Inventory Reporting methodology or IPCC, 2006, Volume 5 (Waste).

Treatment and storage of residues

Residues can be very valuable from the point of view of animal nutrition. Good examples are the citrus pulp that remains after the production of orange and grapefruit juices and the sugar beet pulp after the production of sugar. The residues are often wet products. In a number of instances, the wet residues are dried for easier transport and for additions to compound feed.

Activity data collection: Data shall be collected on the additional processes for residues, such as drying. Data on the use of fossil fuels for drying processes (reversed osmosis, heating etc.) shall be collected.

Emission models and LCI data: In the case of the use of fossil fuels, the same emission factors apply as outlined in the cultivation section, subsection “fossil fuel use”.

11.3.3 Constructing process inventory tables from aggregated or partial data

Previous sections described an ideal situation whereby the LCA practitioner has maximum access to industry information. In practice, this is often not the case, since the LCA practitioner gets only limited information on request or, may find him or herself in a situation in which information is not readily available. The input/output information of a factory may be the most easily available data. This includes the mass balance of inputs of raw materials and energy carriers as well as the outputs of the different co-products and waste. Most of this information is available because it is part of the annual accounting cycle. The input/output information can be used for I/O analysis (see Input/output analysis at factory level).

An I/O analysis at factory level may include different allocation parameters based on properties of the co-products such as price, mass or energy content. In the case of some types of feed processing such as the crushing of oil seeds, dry milling, rendering of animal products and fish products, the I/O analysis provides a particularly good estimate (see Vellinga et al., 2013). .

For production residues such as beet pulp, citrus pulp, spent grain, bread and biscuit leftovers, etc., the upstream production shall not be taken into account. In such cases, a simplified data collection method can be applied by solely focusing on the specific inputs for the post splitting processes, such as drying, specific treatments to improve shelf life, product storage and so on.

This information preferably should be collected from suppliers, but a literature review can help in the data collection process and in filling in of data gaps. The disadvantage of this method is that the LCA practitioner has to rely fully on data regarding specific emissions and resource use that is supplied by the processing industry.. In this case, a consistency check, which should be made when complete information is available as described in the previous sections (see section 11.2) is no longer possible anymore. Therefore, a comparison between industry data and data obtained from literature sources is recommended.

11.3.4 Attributing emissions and resource use to single production units

A manufacturing plant is an industrial site usually consisting of multiple buildings, utilities and production lines that often produce multiple products simultaneously or consecutively.

Information on environmental performance of specific products is, apart from the rare cases when a factory produces a single product through the year without any other non-production related activities, the result of an attribution and allocation process. This process consists of two steps:

- attributing emissions and resource use to separate production units, to be discussed in this section; and

- allocating emissions and resource use to the different co-products produced per production unit, to be discussed in the subsequent section.

The attribution step consists of 3 sub-steps, as explained in the section on allocation (Section 9): These consist of:

1. Assigning inputs and activities directly to specific co-products (post-separation such as drying, purification, storage of the co-product, e.g. beet pulp that needs to be dried, soybean meal that needs to treated further, etc.);
2. Assigning inputs and activities directly to specific production units that still need to be allocated to the different co-products. These are the inputs and activities present before and during the separation process; and
3. Assigning the remaining generic activities that cannot be assigned in **1a)** and **1b)**, such as electricity use for lighting, climate control, internal transport, energy utilities.

After these assignment steps are completed, the data is available on the production unit level. All three steps will be discussed, using the allocation scheme and principles presented, in Section 9. These allocation principles can be applied in a number of situations.

Situation 1: Using the example of drying beet pulp drying according to the allocation scheme, the first question in Box 1, Figure 12 is whether the inputs can be attributed to a single co-product. If this is the case then the inputs for drying can use the line **1a** in the allocation scheme.

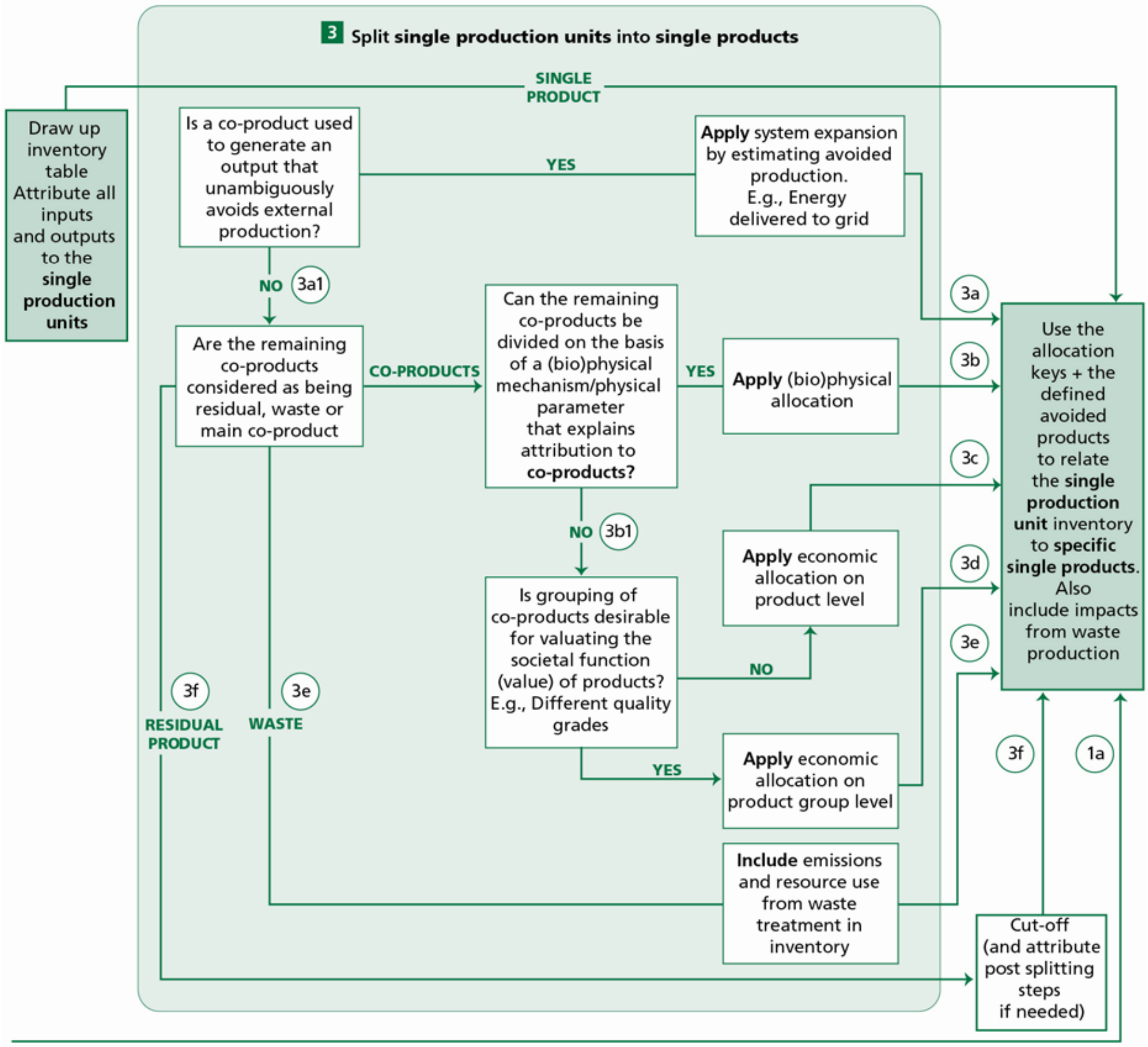
Situation 2: If the energy and other inputs for separating products cannot be attributed to one single co product, but can be attributed to a single production unit and line, then **1b** can be used.

Situation 3: Energy and other inputs that cover generic activities will follow line **1c** in the allocation scheme. The inputs do not involve externally avoided production and hence system expansion will not be applied. The next step is deciding exactly how allocation will be done. Frequently, a simple physical relationship can be applied to allocate emissions to the single production units. This means that line **2b** will be used.

11.3.5 Attributing emissions and resource use of production units to single (co-)products

In Section 11.3.4, all emissions from inputs and resource use have been attributed to the basic production unit. In the processing industry, the input products are split into multiple co-products, including residue products and waste. This means that the total emissions of the production unit need to be attributed to the different co-products. From a formal point of view, at the outset of the procedure, there are not yet waste or residue products, only co-products.

FIGURE 17: ATTRIBUTION TO (CO)-PRODUCTS, PROCESSING



Note: This is the right-hand side of the allocation scheme. The line **1a,** comes directly from the left-hand side of the scheme and is attributed immediately to a co-product.

Applying the right-hand side of the allocation scheme (Figure 19), the first question is whether the co-product is used to produce an output that is unambiguously avoiding external production. In Section 9 on allocation, it has been stated that this is the case only when the co-product is used for energy production that otherwise would be taken from the grid. Therefore, when products are used to replace fossil fuels for producing heat, steam or electricity, system expansion can be applied and line **3a** can be used. The avoided emissions shall be withdrawn from the total emissions calculated in the Section 11.3.2. A good example of this is the surplus production of electricity in a combined heat and power unit sold to an electricity grid.

When system expansion is not applicable, line **3a1** is used and the next question is whether co-products can be considered as waste or as residue products. The definitions of residue and waste are as follows.

DEFINITION OF RESIDUE AND WASTE

Outputs of a production process are considered as a residue if*:*

- sold in the condition as they appears in the process (mostly wet), and contributes very little to the turnover of the company (value of the total flow less than 1 percent; and)
- the upstream and production processes that produce the output are not deliberately modified for the outputs.

Co-products classified as residues should not be considered as "waste" because they have a next user whereas "waste" is material that will be submitted to final waste processing (e.g. incineration and land filling).

When a product is considered a waste, e.g. in the case of POME, the waste generated in palm kernel fruit processing, or in the case of pineapple peel, line **3e** shall be used and the emissions related to the processing of the waste (such as methane emissions from storage, transport to landfill, landfill emissions) must be added to the total emissions calculated in Section 11.3.2.

If a product is to be considered a residue, line **3f** is used and the upstream emissions shall not be attributed to the residue; in contrast, all activities to upgrade the co-product, such as drying, shall be fully attributed to the residue.

For the remaining products that are not considered as residues or waste, it shall be determined whether physical allocation is possible on the basis of an underlying mechanism or on the properties of the co-products. However, in most cases in a separation process there is no underlying physical model available that can be used to attribute environmental impacts to the specific co-products.

Therefore, allocation of separating raw materials should be based on the economic value, unless co-products are qualified as residue. For external communication (and/or comparison) several alternative allocation options shall be quantified as part of a sensitivity assessment. This means that in the allocation scheme (Figure 19), the line **3b1** should be used. The next question is whether co-products can be aggregated or not. Grouping of products with similar applications can be done and average values for the grouped products can be used to define the allocation factor. One example is dry milling of wheat where an average value for the brans is derived based on average sales prices instead of defining bran qualities per batch of flour milling.

Physical allocation at co-production could be applied in some situations where animal-based products are split into multiple co-products (animal slaughter by-products or splitting of dairy products), according to the same line of reasoning used for the bio-physical-based approach for allocation at the dairy farm. The energy content of the co-products reflects the bio-energy inputs along with conversion at the farm (feed and digestion of feed). The processing energy to split the products, however, is not related in this way. So here a subjective element must be included if this processing energy is to be divided in the same way as on the basis of the bio-energy inputs.

In the FeedPrint project (Vellinga et al. 2013), allocation has been made operational for many processed feed materials. This includes the classification of co-products into residue versus co-products and the definition of a practical approach on how to apply the allocation considering the available data.

a) Defining residues and allocating emissions

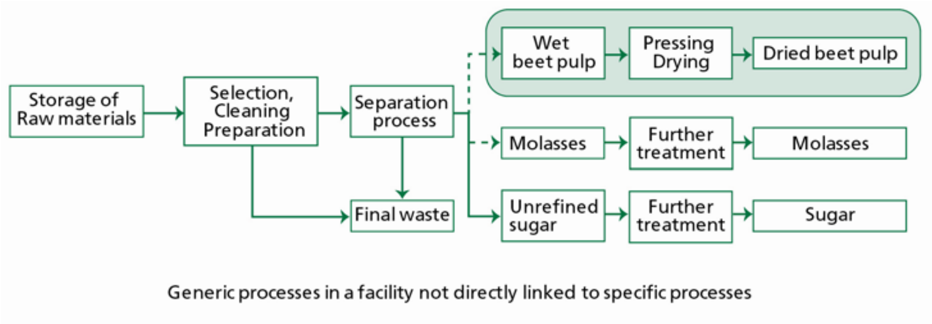
No upstream emissions shall be attributed to residues. For feed raw materials this has been sorted out for the majority of feed materials available on the Dutch market (Vellinga *et al.*, 2013). Applied in a more general sense a classification can be made into three types of residues (Box 5).

BOX 5: CO-PRODUCTS, CONSIDERED AS RESIDUE, TO WHICH NO UPSTREAM ENVIRONMENTAL IMPACTS ARE ALLOCATED

- ***wet co-products from the food consumer*** *products industry* being sold "wet" to animal farms, such as spent grain from breweries, whey from cheese making, leftovers from fruit, vegetables and potato processing industry;
- ***wet co-products from the agricultural commodity*** *industry* such as slaughter by-products, beet pulp from sugar production, citrus pulp, distillers grain from ethanol production; and
- ***dry co-products from the food consumer products*** industry such as chocolate, dry bakery and biscuits products, bread from bakers etc.

Many of these products are further processed to dry feed materials, then stored and transported. However, depending on the vicinity of animal production, these products often may be sold as wet feed products. In any case, although the residue starts out with a zero environmental impact when it appears, the impact of the additional activities (post splitting) shall be included in the LCA of the feed raw materials. Figure 18 illustrates the example of beet pulp, with the blue/grey background area illustrating the post-splitting emissions and resource use that shall be taken into account.

FIGURE 18: DRIED BEET PULP AS AN EXAMPLE OF INCLUDED PROCESSES IN THE LCI OF A RESIDUAL CO-PRODUCT



Applying allocation to "valuable" co-products

Allocation to co-products can be conducted in several ways. Ideally, allocation should be done at the unit process of separation and based on the prices of products at the point of separation.

In practice however, information about intermediate products often is not available. This is especially the case for the prices of intermediate products, or where the determination is very subjective. Moreover the specific LCI information after separation that needs to be attributed to the co-product is often lacking or difficult to attribute.

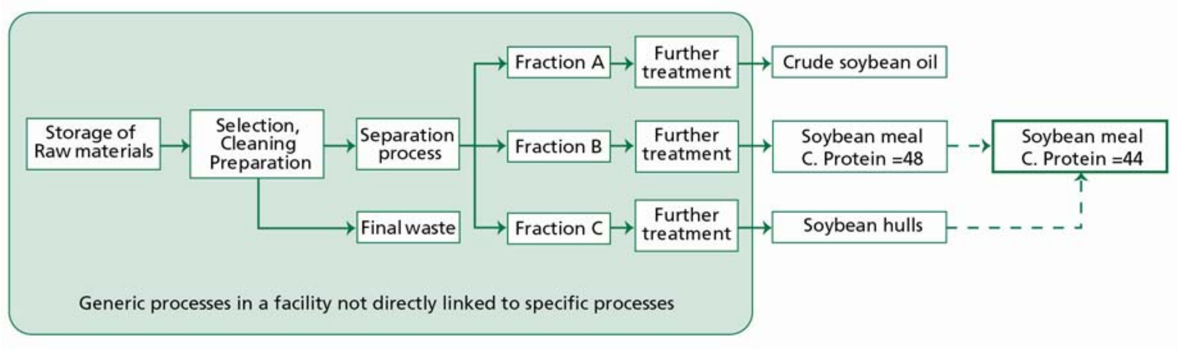
To make allocation feasible, in practice two methods can be applied. The first one, input/output (see "input/output analysis at factory level") is based on a simplification of the more rigorous method described in the section: "Detailed allocation". Due to practical reasons, the first method is the one most often applied.

Input/output analysis at factory level

The most straightforward and often-encountered simplification is to apply allocation on the basis of an input/output analysis of the overall factory or a group of factories (i.e. overall input/output process). This means that the total inputs and related LCI data (at the factory and upstream) are divided among the products on the basis of their relative contribution to overall revenue (in the case of economic allocation).

In fact, this method is not precise enough because differences in processing after separation can cause differences in resource inputs and emissions and as well as valorization of the co-products. If the environmental inputs and emissions and the valorization are similar, and especially if the majority of the impacts occur before separation, (so that the additional impacts after separation are relatively small), the simplified attribution will not change very much (Figure 19 gives example of soybean crushing). Under these conditions, the input/output analysis at factory level gives a rather good estimate for the more precise allocation method, starting at the specific unit process and then including the lifecycle steps afterwards.

FIGURE 19: CO-PRODUCTION FOR WHICH AN INPUT/OUTPUT BASED ALLOCATION CAN BE APPLIED



Note: The entire grey area is assigned on the basis of allocation.

For the following co products I/O analysis based on allocation shall be applied to derive default LCI data.

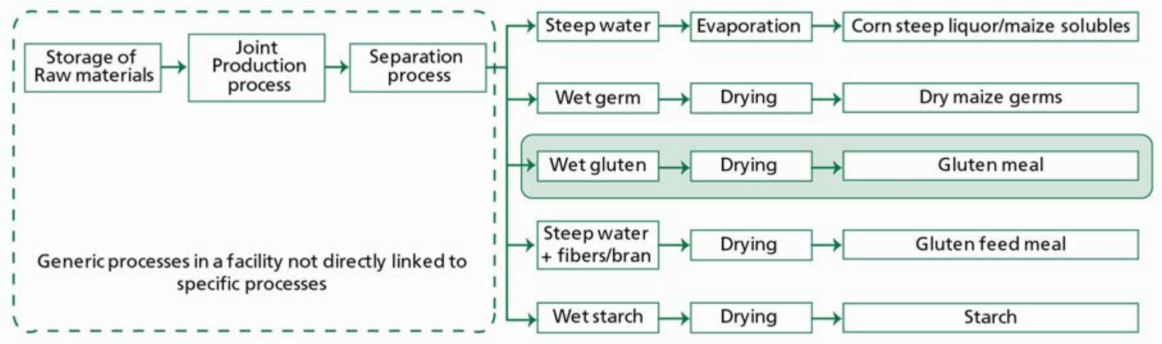
- grain cultivation (straw and grains)
- crushing of oil seeds
- dry milling of grains
- rendering of animal products
- rendering of fish products
- soy protein concentrate production

Detailed economic allocation

The method described in the previous section should in principle not be applied if there are multiple process steps and where the “the after separation processes” differ significantly among the diverse co-products coming from step 1 in terms of resource inputs, emissions or valorization (relatively to pre-processing steps).

This applies, for instance, to wet milling of maize (Figure 20), wheat and potatoes. Here, a more precise allocation based on resource inputs and emissions per co-product specific production route and according to the valorization used provides significantly different results. Since there is a high demand for data for conducting this allocation, and since a significant part of the data is very difficult to obtain, input/output based data are sometimes used (see Vellinga *et al.*, 2013 on recommendations regarding wheat and potato wet milling).

FIGURE 20: WET MILLING OF MAIZE



Note: the allocated emissions and resource use of the joint production before separation (grey area) should be added to the specific assigned emissions and resource use (green area).

Mass and energy content-based allocation (for sensitivity assessment)

The two previous sections about I/O analysis and detailed allocation are applicable mainly in the case of economic allocation, because intermediate prices are not easy to find.

Because the choice of the allocation method can affect the emissions per co-product strongly, a sensitivity assessment applying two alternative allocation methods next to economic allocation are recommended: mass-based and energy content-based allocation.

The mass-based allocation should be done on the basis of the total, dry matter sum of the outputs. This sum is often slightly lower than the inputs due to “unavoidable” processing losses. There are some processes where the sum of the dry matter outputs deviates considerably from the sum of raw materials: for example, by conversion to CO_2 when feedstock carbon is consumed in biological (ethanol production) or chemical processes (calcination of lime). Mostly these gases are residual. In some cases, capture takes place, and if considered as co-products they should be included in the dry matter sum of outputs.

The mass based allocation on a dry matter basis is also the starting point for applying an energy content-based allocation. Per co-product the caloric value is determined on the basis of the LHV of the chemical components (default caloric values per group: fat/oil =37 MJ/kg, protein = 24 MJ/kg, carbohydrates = 18 MJ/kg, water = 0 MJ/kg and not negative, what happens when evaporation is taken into account).

For an economic allocation it is not strictly necessary to consider the dry matter balance of the process, because prices are linked mostly to the co product as it is. It is a good check, however, in the inventory phase of the LCA.

In the sensitivity assessment the same definition of "co-products considered as residual" should be applied.

List of default allocation fractions

To support the consistent performance of feed LCA's, the use of default allocation fractions is recommended (Table 8). The defaults are derived from a global assessment of production processes, using average commodity process in the period 2007–2011.

TABLE 8: LIST OF DEFAULT ALLOCATION FRACTIONS

Process stage	**Product**	**Input**	**In/out (kg/kg)**	**Economic allocation fraction**	**Mass allocation fraction**	**Gross energy allocation fraction**
Cultivation	Barley / Oats	harvested plant	1.67	75%	60%	58%
Cultivation	Barley straw / Oats straw	harvested plant	2.50	25%	40%	42%
Cultivation	Wheat	harvested plant	1.56	79%	64%	64%
Cultivation	Wheat straw	harvested plant	2.78	21%	36%	36%
Dry milling	Wheat germ	Wheat	50.17	3.2%	2.0%	2.4%
Dry milling	Wheat middlings & feed	Wheat	8.03	6.6%	12.5%	10.8%
Dry milling	Wheat bran	Wheat	8.36	6.3%	12.0%	13.8%
Dry milling	Wheat flour	Wheat	1.36	83.9%	73.6%	73.1%
Dry milling	Rice bran	Rice	9.69	3.3%	10.3%	12.1%
Dry milling	Rice husk	Rice	4.85	1.3%	20.6%	16.0%
Dry milling	White rice	Rice	1.45	95.4%	69.0%	71.9%
Wet milling	Wheat bran	Wheat	5.56	8.2%	18.0%	10.9%
Wet milling	Wheat gluten feed	Wheat	12.54	5.0%	8.0%	11.2%
Wet milling	Wheat gluten meal	Wheat	9.96	29.0%	10.0%	9.8%
Wet milling	Wheat starch	Wheat	1.85	54.4%	54.0%	62.4%
Wet milling	Wheat starch slurry	Wheat	10.00	3.4%	10.0%	5.7%
Wet milling	Potato juice concentrated	Potato	8.54	85.7%	11.7%	73.4%
Wet milling	Potato protein	Potato	17.93	1.0%	5.6%	9.8%

Cont.

TABLE 8: LIST OF DEFAULT ALLOCATION FRACTIONS *(CONT.)*

Process stage	Product	Input	In/out (kg/kg)	Economic allocation fraction	Mass allocation fraction	Gross energy allocation fraction
Wet milling	Potato pulp pressed	Potato	11.17	11.5%	8.9%	7.6%
Wet milling	Potato starch dried	Potato	1.36	1.8%	73.8%	9.3%
Crushing (solvent)	Crude soy bean oil	Soy beans	5.11	41.5%	19.6%	39.3%
Crushing (solvent)	Soy bean hulls	Soy beans	13.11	2.9%	7.6%	4.7%
Crushing (solvent)	Soy bean meal (no added hulls)	Soy beans	1.37	55.7%	72.8%	56.0%
Crushing (solvent)	Soy bean meal (hulls added)	Soy beans	1.24	58.5%	80.4%	60.7%
Crushing (cold pressing)	Crude soybean oil	Soy beans	6.22	34.1%	16.1%	29.0%
Crushing (cold pressing)	Soybean expeller	Soy beans	1.19	65.9%	83.9%	71.0%
Crushing (solvent)	Rapeseed meal	Rape seed	1.78	23.9%	56.3%	35.3%
Crushing (solvent)	Crude rapeseed oil	Rape seed	2.29	76.1%	43.7%	64.7%
Crushing (cold pressing)	Rapeseed expeller	Rape seed	1.51	31.8%	66.2%	47.2%
Crushing (cold pressing)	Crude rapeseed oil	Rape seed	2.96	68.2%	33.8%	52.8%
Crushing (cold pressing)	Palm kernels	Palm Fruit Bunches	4.88	13.7%	20.5%	15.4%
Crushing (cold pressing)	Crude palm oil	Palm Fruit Bunches	1.26	86.3%	79.5%	84.6%
Crushing (cold pressing)	Crude palm kern oil	Palm kernels	1.99	89.8%	50.2%	71.4%
Crushing (cold pressing)	Palm kernel expeller	Palm kernels	2.01	10.2%	49.8%	28.6%
Rendering	Food grade fat	Food grade animal material	2.47	73.0%	40.5%	62.0%
Rendering	Greaves meal	Food grade animal material	1.68	27.0%	59.5%	38.0%
Rendering	Fish meal	Landed industry fish	1.23	87.5%	81.5%	67%
Rendering	Fish oil	Landed industry fish	5.40	12.5%	18.5%	33%

List of default allocation fractions

The general model for attributing inventory data of a production unit to co-products per processing stage is expressed by a formula (1), consisting of three parts:

$$(E,R)_A = \frac{(E,R)_{dir,t} - (E,R)_{diravoid,t}}{(P)_{A,t}} + alf_A \times \frac{(E,R)_{com,t} + (E,R)_{comin,t} + (E,R)_{waste,t} - (E,R)_{avoid,t}}{(P)_{A,t}} \quad \text{Formula (1)}$$

Where:

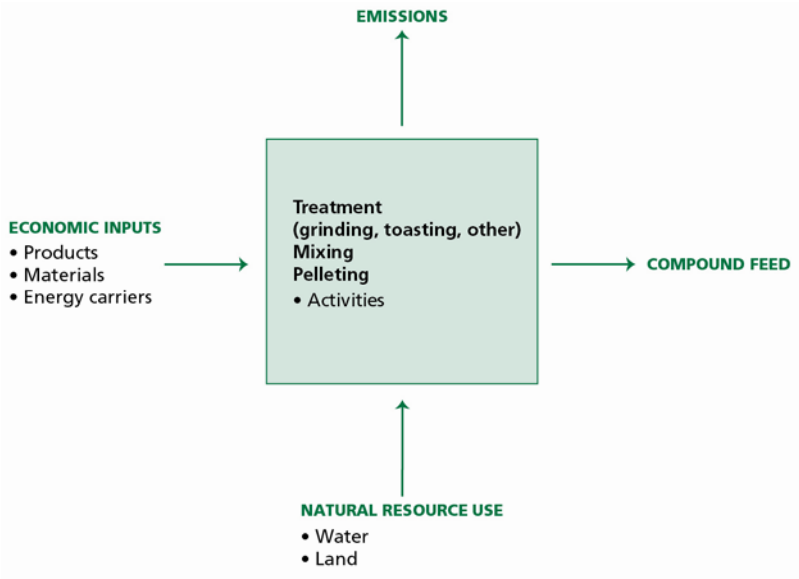
$(E,R)_A$	=	emissions and resource use of product A
$(P)_{A,t}$	=	production of product A in time period t
$(E,R)_{dir,t}$	=	emissions and resource use of processing inputs directly attributed to product A
$(E,R)_{diravoid,t}$	=	emissions and resource use of avoided production directly attributed to product A
alf_A	=	allocation fraction of emissions and resource use attributed to product A
$(E,R)_{com,t}$	=	emissions and resource use of combined processing inputs in time period t
$(E,R)_{comin,t}$	=	emissions and resource use of upstream input products in combined processing in period t
$(E,R)_{avoid,\,t}$	=	emissions and resource use of avoided production coupled to combined production in period t
$(E,R)_{waste,\,t}$	=	emissions and resource use of waste treatment coupled to combined production in period t

11.4 Gate-to-Gate assessment of compound feed production

11.4.1 Definition of the compound feed production system

Compound feed production is in fact the opposite of the processing stage. In compound feed production, many feed materials from the primary production (of plant, animal and non-biogenic origin) or from the processing stage are brought together in a factory to produce compound feed as a final product. Compound feed can consist of different fractions of a wide range of feed materials. Feed materials will be added on the basis of their nutritional characteristics and the specific requirements for the animal type and for its production phase. Some of the incoming products are treated (grinding, toasting etc.) prior to mixing. After the mixing process step, the product can be pelleted or left as a meal (Figure 21). A compound feed factory often produces dozens of different feeds. The composition of these feeds changes through the years depending on availability and on the prices of raw materials. In addition, compound feeds also change as a result of product developments targeting a better feeding/market performance.

FIGURE 21: EMISSIONS AND RESOURCE USE IN COMPOUND FEED PRODUCTION



11.4.2 RELEVANT INPUTS, RESOURCE USE AND EMISSIONS DURING FEED COMPOUNDING

Figure 22 defines the data and the emission factors that have to be collected at the feed compound stage.

FIGURE 22: INVENTORY FLOW CHART FOR COMPOUND FEED PRODUCTION

INVENTORY	EMISSION FACTORS
Define level of analysis depending on goal and scope	Not relevant
Input products (type, fraction)	All upstream emissions of products entering the compound feed unit, irrespective the previous stage • Plant origin • Animal and fish origin • Non-biogenic origin
Storage loss (kg, percentage)	• Correction of upstream emissions
Fuel use (litres, m³, kg, type)	• Per fuel type (CO_2, SO_x, NO_x, crude oil, MJ for all fuels) • Per unit of fuel from databases
Output products (kg, type, DM, nutritive characteristics)	• Not relevant

a) Define level of detail

Depending on the goal and scope of the study, a mass flow balance of the compound feed shall be made. This can range from a specific batch of feed, , to an average feed for a livestock category in a specific production phase (e.g. broilers at the start of their growth period) and on to an overall average of all compound feed produced in a defined period of time.

The practitioner shall decide about the level of detail prior to data collection.

b) Input products

As stated before, compound feed can consist of a large number of feed components, from plant origin, animal origin and from industrial origin (additives, enzymes, synthetic amino acids etc.). The components can come directly from the cultivation stage or from the processing industry.

Activity data collection: Data shall be collected on the mass flow per input product and on the chemical characteristics of the input product. Data collected shall be related to the level of detail as defined in the previous step.

Emission models and LCI data: Information of upstream emissions of all incoming products shall be collected. Primary data from suppliers should be collected, when available. This can be a very laborious step, especially when information regarding a high number of products has to be collected. When primary data are not available or when data collection is too laborious, data shall be taken from databases.

c) Storage loss

Data collection and emission calculation is exactly the same as in the processing stage.

d) Fossil fuel use

The data collection on fossil fuels and the emission factors are exactly the same as is described in the cultivation section, sub-heading “fossil fuels”.

When detailed data are available, a process breakdown shall be made and all inputs of energy and ancillary materials shall be assessed per compound feed (a specific batch, an average for one livestock category or an overall average).

The energy requirements can vary per combination of feed components, per the requirements for grinding and treatment and the choice for either meal or pellets. The environmental impact of the use of electricity and upstream emissions of fuels production differs from country to country and should be collected in as precise a manner as possible. Emissions can be calculated by collecting primary data on energy use for grinding, mixing and pelleting and for necessary internal transports. When a breakdown of the compound feed production process is not possible, an input/ output analysis shall be made preferably on the basis of a period of at least 3 years. In many cases, however, a more aggregated approach is sufficiently accurate because the aggregated approach yields quite similar results. The main contribution of the environmental impact of compound feed comes from the upstream processes and not from the compounding itself.

When primary data are not available, secondary data from internationally accepted databases shall be used, taking into account the region of production and the technology level (BAT or standard methods used).

11.4.3 GENERAL MODEL FOR DERIVING INVENTORY DATA

The average model per step is shown in Figure 23 and expressed by formula 1

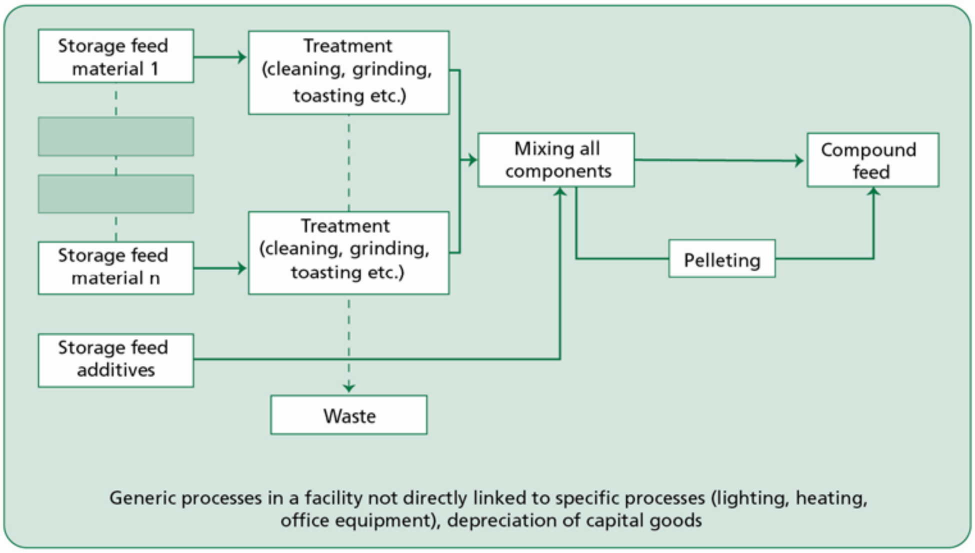
Emissions and Resource Use per compound feed = (Emissions and Resource Use of processing and Inputs)/unit) / (production/unit); a unit in this case can be the batch of compound feed until the average compound feed over a production period.

$$(E,R)_A = \frac{(E,R)_{pro,t} + \sum(E,R)_{inp,t}}{(P)_{A,t}} \quad \text{Formula (1)}$$

Where:

(E,R)p	=	Emissions and Resource Use per product A
(E,R)pro,t	=	Emissions and Resource Use of compound feed production in unit t
∑(E,R)inp,t	=	Emissions and Resource Use of all upstream inputs needed for processing in unit t, corrected for storage losses
(P)A,t	=	Production of product A in time period t

FIGURE 23: PRODUCTION PROCESS OF COMPOUND FEED



11.4.4 APPLYING ALLOCATION

Feed materials are mixed into a compound feed and allocation is not an issue. Allocation also is not needed in the case where a detailed breakdown of the process is made.

11.5 Gate-to-animals' mouth of ration preparation

11.5.1 DESCRIPTION OF FEED PROCESSING AT THE FARM

The animal farm is the final collection point of all feed materials. Larger amounts of feed are bought or produced and stored to be used at the right moment. Other feeds are harvested and fed immediately, without storage, such as fresh grass. In the case of grazing, the feed chain ends with the product standing in the field, ready to be consumed by the animal. All stored feed has to be taken out of storage when it will be used. The animal's requirements define the animal's ration and subsequently the amounts of the various feed materials. Some feed materials need to be processed before feeding, e.g. wheat that will be flattened or ground and fresh grass that will be chopped. After treatment, feed materials can be fed separately to the animals, i.e. subsequently in time or simply placed on top of or next to each other. Feed materials can be combined, manually or mechanically, to form total mixed rations,. The mixed feed can be brought out and placed in front of the animal.

The feeding process at the animal farm is comprised of the following activities:

- ***Reception and storage***: The transport of the feed to the farm, in case of externally bought or produced feed belongs to the end user. Separate guidelines will be defined in the next section.

The various feeds at the farm are often received and stored separately. Energy is often requires for putting feed into storage (silage pits, hay stack, silos). for cooling, and heating etc. And ancillary materials such as plastics, additives etc. are also used. In many cases,, as a consequence of conservation processes or of damages by insects, rodents and others there is a loss of product.

- **Taking out of storage**: After storage on the farm, the products have to be moved from storage to the treatment facility, the feed mixing equipment or directly to the animal. Often only a fraction of the stored feed is removed.. When feed is taken out of storage and then fed immediately to animals, the same machine is used and it nearly impossible to separate the energy use. In other cases energy for removing feed from storage and then providing for internal transport to the next phase is a separate step.
- ***Treatment***: Some feed materials require further treatment at the farm. This may include grinding or flattening of grains, chopping of roughages or other. Treatment always requires energy, whether it involves the use of hand power or machine power. Where machines are used, electricity or fossil fuels are required. During the treatment process, feed losses may occur.
- ***Mixing:*** After feed is taken out of storage and, when relevant, after treatment,, feed can be mixed into a partial mixed ration (PMR) or to a total mixed ration (TMR). In the case of a PMR, a number of diverse feeds, but not all, are mixed to form a homogenous product; in a TMR, all animal feeds are mixed. After mixing, the PMR or the TMR is often fed immediately to the animal, although intermediate storage can also occurs. In most occasions, mixing is done by machines and fossil energy is required. Sometimes part of the input feeds is lost during mixing.
- ***Feeding:*** The energy use for feeding is merged with energy use for removing from storage, treatment or mixing, depending on which of these is the final step before feeding.

Often, on specialized and mechanized farms, many of the processes are handled by machines with an inherent use of fossil fuels or electricity (indirect fossil fuels as well). In many smallholder farms, feeds are mixed and fed to the animals by hand and there is thus no use of fossil energy. The increased energy requirement of farm workers is not taken into account.

The feed residues are not part of the feed chain. This happens at feeding, which is part of the farm process. This implies that emissions per kg of feed must be measured on the basis of the feed allowance. Emissions related to rejected feed also have to be accounted for by the livestock system guidelines.

11.5.2 Relevant emissions and resource use on the farm

Figure 24 defines the data and the emission factors that have to be collected at the farm.

FIGURE 24: INVENTORY FLOW CHART FOR FEED AT THE FARM

INVENTORY	EMISSION FACTORS
Input products (type, fraction)	All upstream emissions of products entering the farm irrespective of previous stage • Cultivation on/off-farm • Processing plant • Compound feed production • Non-biogenic material from trade agents
Storage loss (kg, percentage)	• Storage loss: correction of upstream emissions • NH_3: from protein rich silage from databases
Ancillary materials (kg, type)	• Per type of material: relevant emission factors from databases
Machine use (hours, type)	• Per machine type: average fuel consumption/hour; • Production and maintenance: If data no quality data on emissions and resource use is available, *see Table 4, Section 10.2.2* for guidance on secondary data
Electricity (kWh, origin)	• From grid: IEA database for energy mix • Own production: fuel consumption • Per fuel type (CO_2, SO_x, NO_x, crude oil, MJ for all fuels) from database

a) Input products

The number of feeds used at a farm can be very limited. In extensive grazing systems, such as the pastoral systems, feed rations will mainly consist of grass of different periods of the year, with the animal being feed occasional crop residues or co-products to cope with feed scarcity. On highly specialized dairy farms, different types of roughage are used, partly home-grown and partly externally sourced, co-products from the industry may be bought and compound feed is used. Feed additives may also be bought separately.

Activity data collection: Data shall be collected on the mass flow per feed and on the chemical characteristics of the input product.

Emission models and LCI data: Information of upstream emissions of all incoming products shall be collected. Primary data from suppliers should be collected, when available. This can be a very laborious step, especially when information regarding so many products has to be collected. When primary data are not available or when data collection is too laborious, data shall be taken from databases.

b) Storage loss

This shall be performed in the same way as storage loss at the processing and compounding stages. Almost all nitrogenous components of the feed materials are organic. During conservation and storage part of the nitrogen is emitted as ammonia. This ammonia will be emitted after opening the silage.

Activity data collection: Data shall be collected on the ammonia content of the silage from feed analysis and on the amount of feed in the silage.

Emission models and LCI data: The ammonia content multiplied by the amount of feed in the silage provides the amount of emitted ammonia. When primary data are not available a standard ammonia content of grass silage shall be used from internationally accepted literature or databases.

c) Ancillary materials

Activity data collection: Data shall be collected about the amount of ancillary materials such as plastics, silage additives etc.

Emission models and LCI data: Emission factors shall be derived from internationally accepted databases.

d) Fossil fuel use

The data collection on fossil fuels and the emission factors are exactly the same as is described in the cultivation section, sub-heading "fossil fuels".

Fossil fuels are used in various steps at the farm: storage, removing from storage, treatment, mixing and feeding. With the availability of sufficient data, it will be possible to make a process breakdown and all inputs of energy and ancillary materials shall be assessed per feed component. This is a laborious step and allows for the attribution of the emissions of the different steps to specific feed products. A simplified approach can be considered in which one averages out all fossil fuel use over a group of feed products or all of them. This simplified approach is recommended especially when feeding systems at a farm are simple and have a low energy requirement. When primary data are not available, secondary data from internationally accepted databases shall be used.

e) Machine use

The data collection on machine use and the emission factors are exactly the same as is described in the cultivation section, sub-heading "machine use".

f) Electricity

The data collection on electricity and the emission factors are exactly the same as is described in the cultivation section, sub-heading "electricity".

11.5.3 GENERAL MODEL FOR DERIVING INVENTORY DATA

The average model per step is expressed by formula 2.

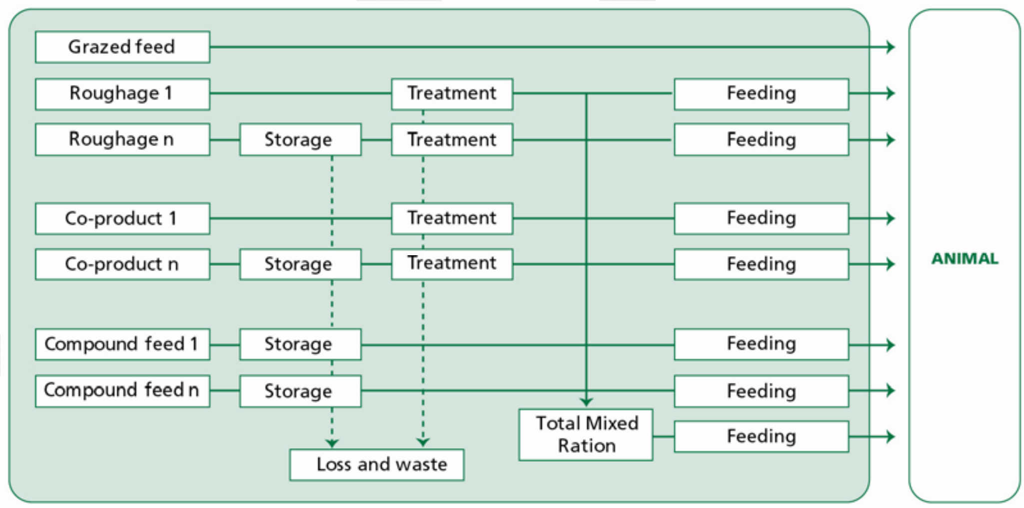
Emissions and Resource Use per compound feed = ((Emissions and Resource Use of processing and Inputs)/unit) / (production/unit); unit in this case may range from a batch of compound feed to the average compound feed over a production period.

$$(E,R)_R = \sum_{i=1}^{n}(E,R)_n \times kg_n \times (1 - loss\ \ )_n^{-1} + (SMTF)_n \quad \text{Formula (2)}$$

Where:

$(E,R)_R$	Emissions and Resource Use of the animals Ration R
$\sum(E,R)_n$	Emissions and Resource Use of all upstream inputs needed for feed n
kg_n	the amount of feed n
$(1 - loss)_n$	The net amount of feed after conservation and storage losses.
$(SMTF)_n$	Emissions and Resource Use, storage, mixing and feeding of feed n

FIGURE 25: FEEDING PROCESS AT THE ANIMAL FARM



Note: The system boundary withn the livestock system is that separating the blue section of ration preparation and the white animal section.

11.6 Intermediate transport and trade

11.6.1 Description of transport and trade

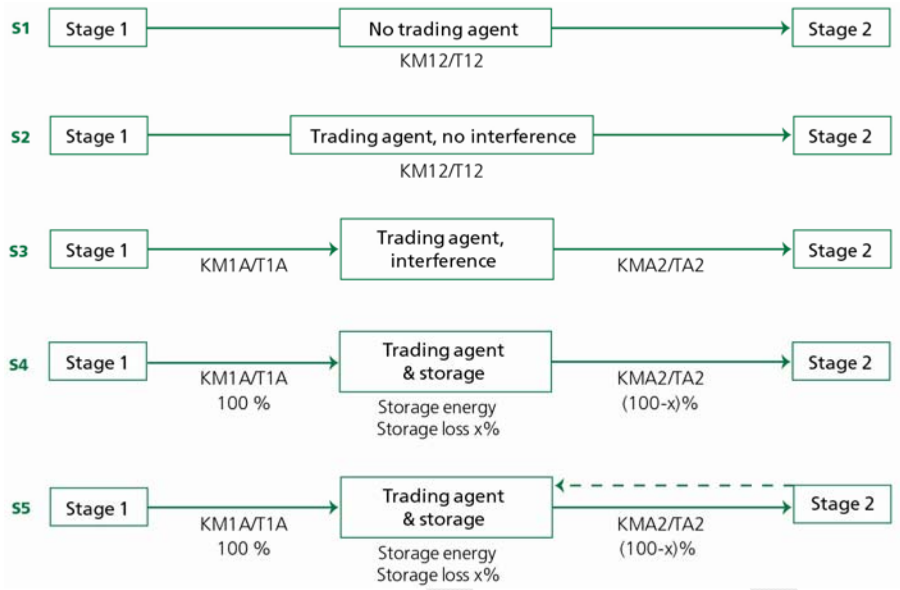
Transport is the connecting link between all phases of production. Transport distance can range from almost nil (from field to farm) to thousands of kilometres in the case of transcontinental transport. The means of transport may be comprised of people or animals carrying feed, animals or tractors pulling carts, lorries and trains transporting feed materials up to hundreds of kilometres, inland vessels for canal transport, coastal ships and transcontinental sea ships. The load ranges from 10 kg (human-powered traction) to 30 000 tons (sea ships). Airfreight is seldom used in the case of feed transport. Transport requires energy, which means food and feed, respectively, in the case of human and/or animal labor. In all other cases, transport requires an energy carrier, such as fuels or electricity. Energy resulting from human and animal labor is not considered in these guidelines.

Transport can be organized by one of the stages itself (e.g. receiving or sending, see scenario S1 in the Figure 26 on Transport and Trade scenarios). However, it can also be organized by specialized transporters and traders, whose role may be limited to brokering between the stages (Scenario 2) in such a way as does not affect the transport itself. But when transport is divided into two phases, as depicted in scenario 3, they also can have a larger role, which is. In the case of traders, intermediate storage may occur, a situation in which traders buy large amounts of feed in periods of low prices, store it and sell it when feed is scarce and prices are high. The same system prevails where feed materials are produced on a continuous basis, occurring when feed demand is seasonal, for example, during the a winter period.. This is depicted in scenario 4. In the case of intermediate storage, losses can occur (due to rodents or fungi) and energy may be required for conditioned storage (heating, cooling, and drying). The losses and energy use shall be taken into account. Transport emissions for the first step from stage 1 to agent A, shall be attributed to the smaller amount (100 – x) percent when leaving the intermediate storage.

Scenario 5 illustrates a minor variation one in which farmers go to the local agent to purchase feed materials which they then transport themselves.

In all cases transport emissions shall be taken into account.

FIGURE 26: TRANSPORT AND TRADE SCENARIOS



Note: KMab = transport distance in kilometres from stage a to b or, Tab = transport between stages/agent a and b.

11.6.2 RELEVANT INPUTS, RESOURCE USE AND EMISSIONS DURING TRANSPORT AND TRADE

FIGURE 27: INVENTORY FLOW CHART FOR FEED DURING TRANSPORT AND TRADE

INVENTORY	EMISSION FACTORS
Transported product (type)	All upstream emissions of products entering the farm irrespective of previous stage • Cultivation on/off-farm • Processing plant • Compound feed production • Non-biogenic material from trade agents
Fossil fuel use (litres, type)	• Per fuel type (CO_2, SO_x, NO_x, crude oil, MJ for all fuels) • Per litre of fuel from databases
Define start and end point of transport	• Define intermediate points of trading agents
• Define means and capacity of transport • Calculate transport distance per type of transport	• Per transport (type) • Relevant emission per ton-km from database • Backhaul
Storage loss (kg, percentage)	Storage loss: correction of upstream emissions
Fossil fuel storage (litres, type)	Per fuel type (CO_2, SO_x, NO_x, crude oil, MJ for all fuels) from databases
Electricity (kWh, origin)	• From grid: IEA database for energy mix • Own production: fuel consumption • Per fuel type (CO_2, SO_x, NO_x, crude oil, MJ for all fuels) from databases

a) Transported product

The type of product can provide information about the type of transport required. Liquid products require tankers. Some products are susceptible to microbial activity and consequently heating of the product, or contamination with other products, is not allowed.

Activity data collection: Data shall be collected regarding the type of the transported product. When primary data about fossil fuel for transport are available, data shall be collected about the amount of transported product in order to calculate the fuel use per ton of product.

Emission models and LCI data: Not relevant.

b) Fossil fuel use for transport

The data collection on fossil fuels and the emission factors are exactly the same as is described in the cultivation section, sub-heading "fossil fuels".

Emission models and LCI data: When primary data on fossil fuel use are to be collected, information about the emission factor regarding the production and maintenance of transport means shall be made available.

When primary data on fossil fuel use for transport are not known, secondary data shall be amasses from databases. When secondary data on transport emissions are applied, the emissions of production and maintenance have already been incorporated into the emission factor per ton per kilometre. The next three steps are required when primary data on fuel use are not present.

c) Start- and endpoint of transport

Activity data collection: Data shall be collected about the start- and endpoint of the transport. This is required in order to calculate the transport distance.

Emission models and LCI data: Not relevant.

d) Define transport means and capacity

There is wide range of possible means of transport with a broad range of transport capacity. They all have their own emission levels with regard to transport, production and maintenance.

Activity data collection: Data shall be collected about the means of transport between start- and endpoint. When multiple means of transport are used, the starting- and endpoint per means shall be identified.

Per means of transport data shall be collected (or defined):

- the capacity of the means of transport;
- the load factor per transport; and

- the empty transport distance (backhaul) per transport. When the transport means is returning empty for a new load, all "empty" kilometres shall be allocated to the transported product.

Emission models and LCI data: Emission factors per transport means can be derived from databases. Assumptions on backhaul shall be checked and emission factors shall be corrected when the assumptions differ from the transport under study.

e) Calculate transport distance

Per transport means a start- and endpoint has been defined.

Activity data collection: Data shall be collected about the distance between every start- and endpoint in the whole chain of transport. The methodology for calculating transport distances is defined in Annex "Transport and trade".

Emission models and LCI data: Emission can be calculated by multiplying the kilometres per transport means by the emission factor per transport means and accumulating all emissions for transporting the product from the original start point to the final endpoint.

f) Storage loss

This shall be calculated in the same way as storage loss at the processing stage and compounding stage.

g) Fossil fuel use for storage

The data collection on fossil fuels and the emission factors are exactly the same as described in the cultivation section, sub-heading "fossil fuels".

h) Electricity use for storage

The data collection on electricity and the emission factors are exactly the same as described in the cultivation section, sub-heading "electricity".

11.6.3 GENERAL MODEL FOR DERIVING INVENTORY DATA

The average model per step is expressed by formula 3.

$$(E,R)_T = \left(\sum_{i=1}^{a} km_a \times \left(\frac{EF}{tonkm}\right)_a\right) \times (1 - loss_a)^{-1}$$

$$+ \left(\sum_{i=1}^{b} km_b \times \left(\frac{EF}{tonkm}\right)_b\right) + (FF)_{st} + EL_{st} \qquad \text{Formula (3)}$$

Where:

$(E,R)_T$	Emissions and resource use of the transport T
$\sum Km_a * (EF/tonkm)_a$	Transport emissions of step a (to the agent) in the transport and trade scheme for the different kinds of transport used
$\sum Km_b * (EF/tonkm)_b$	Transport emissions of step b (from the agent) in the transport and trade scheme for the different kinds of transport used
EF/tonkm	Emissions factor per ton per kilometre for a specific means of transport
km_a	the transport distance between the starting point and the endpoint of the agent. In case of suffix b, it is the distance from the agent to the next endpoint.
$(1 - loss)_n$	Net amount of feed after conservation and storage losses
$(FF)_{st}$	Fossil fuel emissions, for storage
$(EL)_{st}$	Electricity emissions, for storage

12 INTERPRETATION OF LCA RESULTS

Interpretation of the results of the study serves two purposes (European Commission, 2010):

At all steps of the LCA, the calculation approaches and data shall match the goals and quality requirements of the study. In this sense, interpretation of results may inform an iterative improvement of the assessment until all goals and requirements are met.

The second purpose of the interpretation is to develop conclusions and recommendations, e.g. in support of environmental performance improvements. The interpretation entails three main elements detailed in the following subsections: "Identification of important issues," "Characterizing uncertainty" and "Conclusions, limitations and recommendations".

12.1 Identification of key issues

Identifying important issues encompasses the identification of most important impact categories and life cycle stages, as well the sensitivity of results to methodological choices.

The first step is to determine the life cycle stage processes and elementary flows that contribute most to the LCIA results, as well as the most relevant impact categories. To do this, a contribution analysis shall be conducted. It quantifies the relative contribution of the different stages/categories/items to the total result. Such contribution analysis can be useful for various interests, such as focusing data collection or mitigation efforts on the most contributing processes.

Secondly, the extent to which methodological choices such as system boundaries, cut-off criteria, data sources, and allocation choices affect the study outcomes shall be assessed, especially impact categories and life cycle stages having the most important contribution. In addition, any explicit exclusion of supply chain activities, including those that are excluded as a result of cut-off criteria, shall be documented in the report. Tools that should be used to assess the robustness of the footprint model include (European Commission, 2010):

- Completeness checks: evaluate the LCI data to confirm that it is consistent with the defined goals, scope, system boundaries, and quality criteria and that the cut-off criteria have been met. This includes completeness of process (i.e. at each supply chain stage, the relevant processes or emissions contributing to the impact have been included) and exchanges (i.e. all significant energy or material inputs and their associated emissions have been included for each process).
- Sensitivity checks: assess the extent to which the results are determined by specific methodological choices, and the impact of implementing alternative, defensible choices where these are identifiable. This is particularly important with respect to allocation choices. It is useful to structure sensitivity checks for each phase of the study: goal and scope definition, the life cycle inventory model, and impact assessment.
- Consistency checks: ensure that the principles, assumptions, methods and data have been applied consistently with the goal and scope throughout the study. In particular, ensure that the following are addressed: (i) the data quality along the life cycle of the product and across production systems, (ii) the methodological choices (e.g. allocation methods) across production systems and (iii) the application of the impact assessments steps with the goal and scope.

12.2 Characterizing uncertainty

This section is related to *Section 10.3*, data quality. Several sources of uncertainty are present in LCA. First is knowledge uncertainty which reflects limits of what is known about a given datum, and second is process uncertainty which reflects the inherent variability of processes. We can reduce knowledge uncertainty by collecting more data. We may reduce process uncertainty by breaking complex systems into smaller parts or aggregations, but inherent variability cannot be eliminated completely. Third, the characterization factors that are used to combine the large number of inventory emissions into impacts also bring uncertainty into the estimation of impacts. In addition, there is bias introduced if the LCI model is missing processes, or may have larger flows than actually present.

Variation and uncertainty of data should be estimated and reported. This is important because results based on average data (i.e. the mean of several measurements from a given process – at a single or multiple facilities) or using LCIA characterization factors with known variance do not reveal the uncertainty in the reported mean value of the impact. Uncertainty may be estimated and communicated quantitatively through a sensitivity and uncertainty analysis and/or qualitatively through a discussion. Understanding the sources and magnitude of uncertainty in the results is critical for assessing robustness of decisions that may be made based on the study results. When mitigation action is proposed, knowledge of the sensitivity to, and uncertainty associated with the changes proposed provides valuable information regarding decision robustness, as described in Table 9. At a minimum, efforts to accurately characterize stochastic uncertainty and its impact on the robustness of decisions should focus on those supply chain stages or emissions identified as significant in the impact assessment and interpretation. Where reporting to third parties, this uncertainty analysis shall be conducted and reported.

TABLE 9: GUIDE FOR DECISION ROBUSTNESS FROM SENSITIVITY AND UNCERTAINTY

Sensitivity	Uncertainty	Robustness
High	High	Low
High	Low	High
Low	High	High
Low	Low	High

12.2.1 MONTE CARLO ANALYSIS

In a Monte Carlo analysis, parameters (LCI) are considered as stochastic variables with specified probability distributions, quantified as probability density functions (PDF). For a large number of realizations, the Monte Carlo analysis creates an LCA model with one particular value from the PDFs of every parameter and calculates the LCA results. The statistical properties of the sample of LCA results across the range of realizations are then investigated. For normally distributed data, variance is typically described in terms of an average and standard deviation. Some databases, notably EcoInvent, use a lognormal PDF to describe the uncertainty. Some software tools (e.g. SimaPro, OpenLCA) allow the use of Monte Carlo simulations to characterize the uncertainty in the reported impacts as affected by the uncertainty in the input parameters of the analysis.

12.2.2 Sensitivity analysis

Choice-related uncertainties arise from methodological including modelling principles, system boundaries and cut-off criteria, choice of footprint impact assessment methods, and other assumptions related to time, technology, geography, etc. Unlike the LCI and characterization factors, they are not amenable to statistical description, but the sensitivity of the results to these choice-related uncertainties can be characterized through scenario assessments (e.g., comparing the footprint derived from different allocation choices) and/or uncertainty analysis (e.g. Monte Carlo simulations).

In addition to choice-related sensitivity evaluation, the relative sensitivity of specific activities (LCI datasets) measures the percentage change in impact arising from a known change in input parameter (Hong et al., 2010)

12.2.3 Normalization

According to ISO 14044, normalization is an optional step in impact assessment. Normalization is a process in which an impact associated with the functional unit is compared against an estimate of the entire regional impacts in that category (Sleeswijk *et al*., 2008). For example, livestock supply chains have been estimated to contribute 14.5 percent of global anthropogenic greenhouse gas emissions (Gerber *et al*., 2013). Similar assessments can be made at regional or national scales, provided that a reasonably complete inventory of all emissions in that region which contribute to the impact category exists. Normalization provides an additional degree of insight into those impacts for which significant improvement would result in a significant improvement for the region in question, and can help decision-makers to focus on supply chain hotspots for which improvement will result in the greatest overall environmental benefit.

12.3 Conclusions, Recommendations and Limitations

The final part of interpretation is to draw conclusions derived from the results, pose answers to the questions raised in the goal and scope definition stage, and recommend appropriate actions to the intended audience, within the context of the goal and scope, explicitly accounting for limitations to robustness, uncertainty and applicability.

Conclusions derived from the study should summarize supply chain "hot spots" derived from the contribution analysis and the improvement potential associated with possible management interventions. Conclusions should be given in the strict context of the stated goal and scope of the study, and any limitation of the goal and scope can be discussed *a posteriori* in the conclusions.

As required under ISO 14044:2006, if the study is intended to support comparative assertions (i.e. claims asserting difference in the merits of products based the study results), then it is necessary to fully consider whether differences in method or data quality used in the model of the compared products impair the comparison. Any inconsistencies in functional units, system boundaries, data quality, or impact assessment shall be evaluated and communicated.

Recommendations are based on the final conclusion of the LCA study. They shall be logical, reasonable, plausible founded and strictly relate to the goal of the study. Recommendations shall be given jointly with limitations in order to avoid their misinterpretation beyond the scope of the study.

12.4 Use and comparability of results

It is important to note that these guidelines refer only to a partial LCA and that where results are required for products throughout the whole life cycle then it is necessary to link this analysis with relevant methods for secondary processing through to consumption and waste stages (e.g. EPD 2012; PAS 2395 2013 Draft). However, they can be used to identify hot-spots in the cradle-to-primary-processing stages (which are major contributors to emissions across the whole life cycle) and assess potential GHG reduction strategies.

12.5 Good practice in reporting LCA results

The LCA results and interpretation shall be fully and accurately reported, without bias and consistent with the goal and scope of the study. The type and format of the report should be appropriate to the scale and objectives of the study and the language should be accurate and understandable by the intended user so as to minimise the risk of misinterpretation.

The description of the data and method shall be included in the report in sufficient detail and transparency to clearly show the scope, limitations and complexity of the analysis. The selected allocation method used shall be documented and any variation from the recommendations in these guidelines shall be justified.

The report should include an extensive discussion of the limitations related to accounting for a small numbers of impact categories and outputs. This discussion should address:

- Negative impacts on other (non GHG) environmental criteria;
- Positive environmental impacts (e.g., on biodiversity, landscape, carbon sequestration);
- Multifunctional outputs other than production (e.g., economic, social, nutrition);

If intended for the public domain, a communication plan shall be developed to establish accurate communication that is adapted to the target audience and defensible.

12.6 Report elements and structure

The following elements should be included in the LCA report:

- Executive summary typically targeting a non-technical audience (e.g. decision-makers), including key elements of goal and scope of the system studied and the main results and recommendations while clearly giving assumptions and limitations;
- Identification of the LCA study, including name, date, responsible organization or researchers, objectives of/reasons for the study and intended users;
- Goal of the study: intended applications and targeted audience, methodology including consistency with these guidelines;
- Functional unit and reference flows, including overview of species, geographical location and regional relevance of the study;
- System boundary and unit stages (e.g. cradle-to-gate cultivation of feedcrop)
- Materiality criteria and cut-off thresholds;
- Allocation method(s) and justification if different from the recommendations in these guidelines;
- Description of inventory data: representativeness, averaging periods (if used), and assessment of quality of data;
- Description of assumptions or value choices made for the production and processing systems, with justification;
- LCI modelling and calculating LCI results;
- Results and interpretation of the study and conclusions;
- Description of the limitations and any trade-offs;
- If intended for the public domain the report should also state whether or not the study was subject to independent third-party verification.

12.7 Critical review

Internal review and iterative improvement should be carried out for any LCA study. In addition, if the results are intended to be released to the public, third-party verification and/or external critical review shall be undertaken (and should be undertaken for internal studies) to ensure that:

- the methods used to carry out the LCA are consistent with these guidelines and are scientifically and technically valid;
- the data and assumptions used are appropriate and reasonable;
- interpretations take into account the complexities and limitations inherent in LCA studies for on-farm and primary processing;
- the report is transparent, free from bias and sufficient for the intended user(s).

The critical review shall be undertaken by an individual or panel with appropriate expertise, e.g. suitably qualified reviewers from agricultural industry or government or non-government officers with experience in the assessed supply chains and LCA. Independent reviewers are highly preferable.

The panel report and critical review statement and recommendations shall be included in the study report if publicly available.

References

Alexandratos N, Bruinsma J. 2012 *World agriculture towards 2030/2050: the 2012 revision*. ESA Working paper Rome, FAO.

Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. 2009. *How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050*. WWF-UK.

British Standards Institution (BSI). 2011 Publically Available Specification 2050:2011 Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. PAS 2050:2.

European Commission, 2010. *ILCD Handbook: General Guide for Life Cycle Assessment–Detailed Guidance*, Eur 24708. ed, JRC, IES. Joint Research Centre,Institute for Environment and Sustainability.

Finnveden G, Hauschild MZ, Ekvall T, et al. 2009 Recent developments in Life Cycle Assessment. *Journal of Environtal Management* 91:1–21. doi: 10.1016/J.Jenvman.2009.06.018.

Food SCP RT 2013 ENVIFOOD *Protocol, Environmental Assessment of Food and Drink Protocol.* 1–64.

Goedkoop, M.; Heijungs, R.; Huijbregts, M.; DeSchryver, A.; Struijs, J.; and VanZelm, R. 2012 RECIPE 2008: A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level First edition (revised) Report I: Characterization.

Guinée, J.B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Wegener Sleeswijk, A., Suh, S., Udo de Haes, H.A., de Bruijn, H., van Duin, R., Huijbregts, M.A.J., Lindeijer, E., Roorda, A.A.H., van der Ven, B.L., Weidema, B.P. (Eds.), 2002. *Handbook on Life Cycle Assessment*; *Operational Guide to the ISO Standards*. Leiden, The Netherlands, Institute for Environmental Sciences.

Hauschild, M.Z.; Goedkoop, M.; Guinee, J.; Heijungs, R.; Huijbregts, M. Jolliet, O.; Margni, M.; DeSchryver, A.; Humbert, S.; and Laurent, A. (2013) Identifying best existing practice for characterization modelling in life cycle assessment. *The International Journal of Life Cycle Assessment,* 18, pp 683-697.

Henderson, B. et al. *Forthcoming*. Greenhouse gas mitigation in grazing lands: modelling carbon sequestration and N_2O emission mitigation in the world's rangelands and pasturelands.

Huijbregts MAJ, Norris GA, Bretz R, et al. 2001 Framework for modelling data uncertainty in life cycle inventories. *Int J Life Cycle Assess* Vol. 6. pp.127–132 Springer.

IDF 2010. A common carbon footprint approach for dairy: The IDF guide to standard lifecycle assessment methodology for the dairy sector. *Bulletin of the International Dairy Federation* 445/2010. 46p.

ILCD (2010). ILCD Handbook: Analysis of existing Environmental Impact Assessment methodologies for use in Life Cycle Assessment European Commission. Joint Research Center, European Union. 115p.

IPCC 2006a IPCC Guidelines for National Greenhouse Gas Inventories: Volume 4: *Agriculture, Forestry and other Land Use. Intergovernmental Panel on Climate Change.* Paris, France. Available at:.http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.htm.

IPCC 2006b IPCC Guidelines for National Greenhouse Gas Inventories: Volume 5, chapter 2: *Stationary combustion Intergovernmental Panel on Climate Change*. Paris, France. Available at:.http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.htm.

IPCC 2006c Changes in Atmospheric Constituents and in Radiative Forcing, Table 2.14. available at http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html#table-2-14.

ISO 14044 2006 *Environmental management – Life cycle assessment – Requirements and guidelines*. British Standards Institution, UK. EN ISO 14044:2006(E). ISBN 0 580 49022. 46p.

ISO/TS 14067 2013 *Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification and communication*. International Organisation of Standards. ISO/TC 207/SC 7.

ISO (2006b) 14025 *Environmental labels and declarations* — Type III environmental declarations — Principles and procedures.

ISO (2006c) 14040 *Environmental management-life cycle assessment-principles and framework.*

MacLeod, M., Gerber, P., Opio, C., Falcucci, A., Tempio, G., Henderson, B., Mottet, A., Steinfeld, H. 2013 *Greenhouse gas emissions from pig and chicken supply chains*. Report, Rome, September 2013 FAO.

Milà-i-Canals, L, Azapagic A, Doka G, et al. (2011) Approaches for Addressing Life Cycle Assessment Data Gaps for Bio-based Products. *Journal of Industrial Ecology*, 15:707–725. doi: 10.1111/j.1530-9290.2011.00369.

NRC. 2001 *Nutrient requirements of dairy cattle*; 7th Ed., Nat. Acad. Press, Washington, DC).

Opio, C., Gerber, P., MacLeod, M., Falcucci, A., Henderson, B., Mottet, A., Tempio, G., Steinfeld, H. 2013 *Greenhouse gas emissions from ruminant supply chains.* Report FAO, Rome, September 2013.

Opio, C., Gerber, P. and Steinfeld, H. 2012. Livestock and the environment: addressing the consequences of livestock sector growth. Advances in Animal Biosciences (2011), 2:3, pp 601–607.

Reap J, Roman F, Duncan S, Bras B. 2008 A survey of unresolved problems in life cycle assessment. *Int J Life Cycle Assess* 13:374–388. doi: 10.1007/s11367-008-0009-9.

Sleeswijk, A.; VanOers, L.F.C.M.; Guinee, J.B.; Struijs, J.; Huijbregts, M.A.J. 2008 Normalisation in product life cycle assessment: An LCA of the global and European economic systems in the year 2000. *Science of the Total Environment* 390 (2008) 227-240.

Vellinga, Th.V.; Blonk, H.; Marinussen, M.; VanZeist, W.J.; De Boer, I.J.M.; and Starmans, D. 2013 Methodology used in FeedPrint: a tool quantifying greenhouse gas emissions of feed production and utilization. *Report Wageningen UR Livestock research* 674. 120 pp.

WRI-WBCSD 2011. *Greenhouse Gas Protocol - Product Life Cycle Accounting and Reporting Standard.*

APPENDICES

Appendix 1: Review of studies on methodologies focused on the feed production chain

Introduction

All studies analyzing the environmental impacts of livestock products deal with feed and the related production chain. Feed is an intermediate product in the complete value chain of livestock products. This review will be limited to studies that focus on the feed production chain or that provide an overview at the sector or regional level. Farm specific studies can analyze specific situations whereas sector and regional studies have to develop more general methods to calculate the environmental impact of feed products.

For this we selected the following studies: Berglund et al., 2009; Capper et al., 2009; Cederberg et al., 2013; Flysjö et al., 2008; Leip et al., 2010; Nijdam et al., 2012; Powell et al., 2013; Thoma et al., 2013; Thomassen et al., 2008; van Middelaar et al., 2013; Vellinga et al., 2012; Vergé et al., 2013; Weiss et al., 2012; Whittaker et al., 2013; Zehetmeier et al., in press.

In this document, we will identify the common approaches as well as point out differences in methodological and modelling choices in LCA studies examining feed production chains separately or in overall livestock system studies.

Results

Scope and goal

A number of studies focused on GHG emissions of feed (ingredients) These include: Cederberg et al., 2013; van Middelaar et al., 2013; Vellinga et al., 2012; Flysjö et al., 2008; Whittaker et al., 2013. Others had a broader scope such as the overall livestock sector in the EU (Leip et al., 2010; Weiss et al., 2012) and North America (Nijdam et al., 2012); dairy production in the US (Thoma et al., 2013; Capper et al., 2009) or Germany (Zehetmeier et al, in press); dairy products in Canada (Vergé et al., 2013); comparisons between conventional and organic farming (Thomassen et al., 2008), or the relation between milk and manure at the global level (Powell et al., 2013). One additional study presents an overview of the methods used for estimating GHG emissions in LCA/CFP of livestock products (Cederberg et al., 2013).

The scope of this study is that of creating an overview of emissions, to develop a methodology and to or discuss methodological issues and to compare systems (Table 1)

TABLE 1: CLASSIFICATION OF THE REVIEWED LITERATURE TO OVERVIEW (SECTORIAL AND REGIONAL), COMPARISON (BETWEEN SYSTEMS, OVER TIME) AND METHODOLOGY DEVELOPMENT

Scope	**Literature**
Overview	Leip *et al.,* 2012; Weiss *et al.,* 2012; Thoma *et al.,* 2013; Vergé et al., 2013; Powell *et al.,* 2012;
Comparison	Capper, 2009; 1944 versus 2007; Thomassen et al., 2008; conventional versus organic; Whittaker et al., 2013: models
Methodology	Berglund et al., 2008; Flysjö and Cederberg, 2009; Vellinga et al., 2013; Middelaar et al., 2013; Zehetmeier et al., 2013; Cederberg et al., 2013

System boundaries

With regard to system boundaries, the situation remains unclear. All studies speak about the cradle-to-X approach. Most of the studies, explicitly mention upstream emissions such as the production of synthetic fertilizer as an example of the cradle-to-X approach. Machine production and maintenance is explicitly mentioned by Vergé et al. (2013) and Vellinga et al. (2013). In contrast, Capper (2009) does not mention anything about upstream emissions. Whittaker et al. (2013) show that because of different methods of calculation s, there is a wide range in perceptions regarding upstream emissions.

Functional unit

A number of studies focus on the feed production chain and explicitly choose a kg of feed as the functional unit (Middelaar et al. (2013); Vellinga et al. (2013), Berglund et al. (2008), Flysjö and Cederberg (2009). All others analyse livestock systems, choosing a unit that lies beyond the feed production chain.

Allocation

Allocation in the feed production chain. Some studies explicitly mention the allocation method in the feed production chain. Thomassen et al. (2008), Flysjö et al. and Cederberg et al. (2009), Thoma et al. (2013) and Vellinga et al. (2013) explicitly mention economic allocation. Berglund et al. (2008) show mass and economic allocation for processing feed materials, whereas Leip et al. (2010) use physical allocation based on the N content for allocation between grain and straw. Gerber *et al.* (2013) use physical allocation for grain and straw in developing countries where straw is used as feed and economic allocation in industrialized countries where straw is used as bedding material.

Environmental impacts

Most of the studies use only global warming as an environmental impact; only Thomassen et al. (2008) include acidification, eutrophication, land occupation and energy use. Nijdam et al. (2012) also look at land occupation in their review.

Uncertainty

All kinds of uncertainty in the studies have been mentioned. These include epistemic uncertainty, variability uncertainty, model uncertainty, parameter uncertainty, uncertainty due to methodological choices and spatial and temporal variability. But no systematic uncertainty analysis is performed.

Conclusions

Only a limited number of LCA studies focus specifically on the feed chain; in most studies, the feed supply chain is only a part of the analysis of a broader livestock system. In contrast, the feed chain LCA studies that do exist focus on methodology development and on creating an overview of GHG emissions of feed products. There is no study covering as wide range of situations as the LEAP guidelines propose, but there is no doubt that the various feed chain studies act as very important building blocks.

References

Berglund, M., C. Cederberg, C. Clason, M. Henriksson, and L. Törner. 2009. Jordbrukets Klimatpaverkan - underlag för att beräkna växthusgasutsläpp pa gardsnivá och nulägesanalyser av exemplgardar. In *Delrapport I Joker-projektet*: Hushallnings Sallskapet.

Capper, J. L., R. A. Cady, and D. E. Bauman. 2009. The environmental impact of dairy production: 1944 compared with 2007. *Journal of Animal Science* 87 (6): 2160-2167.

Cederberg, C., M. Henriksson, and M. Berglund. 2013. An LCA researcher's wish list--data and emission models needed to improve LCA studies of animal production. *Animal* 7 Suppl 2: 212-9.

Flysjö, A., C. Cederberg, and I. Strid. 2008. LCA-databass för konventionella fodermedel - miljöpaverkan i samband med produktion. In *SIK rapport 772* Sik, SLU, Svenskmjölk.

Leip, A., F. Weiss, T. Wassenaar, I. Perez, T. Fellmann, P. Loudjani, F. Tubiello.. 2010. *Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions* (GGELS) – Final Report. European Commission, Joint Research Centre. JOINT RESEARCH CENTRE, European Commission.

Nijdam, D., T. Rood, and H. Westhoek. 2012. The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. *Food Policy* 37 (6): 760-770.

Powell, J. M., M. MacLeod, T. V. Vellinga, C. Opio, A. Falcucci, G. Tempio, H. Steinfeld, and P. Gerber. 2013. Feed–milk–manure nitrogen relationships in global dairy production systems. *Livestock Science* 152 (2–3): 261-272.

Thoma, G., J. Popp, D. Nutter, D. Shonnard, R. Ulrich, M. Matlock, D. S. Kim.2013. Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. *International Dairy Journal* 31: S3-S14.

Thomassen, M. A., K. J. van Calker, M. C. J. Smits, G. L. Iepema, and I. J. M. de Boer. 2008. Life cycle assessment of conventional and organic milk production in the Netherlands. *Agricultural Systems* 96 (1-3): 95-107.

Tufvesson, L. M., P. Tufvesson, J. M. Woodley, and P. Borjesson. 2013. Life cycle assessment in green chemistry: overview of key parameters and methodological concerns. *International Journal of Life Cycle Assessment* 18 (2): 431-444.

van Middelaar, C. E., C. Cederberg, T. V. Vellinga, H. M. G. van der Werf, and I. J. M. de Boer. 2013. Exploring variability in methods and data sensitivity in carbon footprints of feed ingredients. *International Journal of Life Cycle Assessment* 18 (4): 768-782.

Vellinga, T., and J. d. Boer. 2012. LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization Cultivation of forage and roughage. Background data report on cultivation, version 2012, part 6/7: forage and roughage. In *LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization Cultivation of forage and roughage.* , edited by M. Marinussen: Blonk Consultants.

Vergé, X. P. C., D. Maxime, J. A. Dyer, R. L. Desjardins, Y. Arcand, and A. Vanderzaag. 2013. Carbon footprint of Canadian dairy products: Calculations and issues. *Journal of Dairy Science* 96 (9): 6091-6104.

Weiss, F., and A. Leip. 2012. Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. *Agriculture, Ecosystems & Environment* 149 (0): 124-134.

Whittaker, C., M. C. McManus, and P. Smith. 2013. A comparison of carbon accounting tools for arable crops in the United Kingdom. *Environmental Modelling & Software* 46: 228-239.

Zehetmeier, M., M. Gandorfer, H. Hoffmann, U. K. Müller, I. J. M. de Boer, and A. Heißenhuber. (in press) The impact of uncertainties on predicted GHG emissions of dairy cow production systems. *Journal of Cleaner Production* (0).

Appendix 2: Feed Characteristics

All feed characteristics are based on (chemical) analyses.. They provide the basis for the calculation of animal- and country-specific energy (digestible, metabolizable or net energy) and protein (crude protein, digestible protein and other values) content. Using the associated values, With, detailed nutritional models can be applied to calculate animal requirements, related feed intake, retention and excretion of nutrients.

TABLE 2: EXTENDED LIST OF FEED CHARACTERISTICS FOR DIFFERENT LIVESTOCK SPECIES

Name English	Ruminants	Pigs	layers	Broilers
Dry Matter reference	X	X	X	X
Dry Matter	X	X	X	X
Crude Ash	X	X	X	X
Crude Protein	X	X	X	X
Crude fat, no hydrolysis	X	X	X	X
Crude fat, acid hydrolysis	X	X	X	X
Crude fibre	X	X	X	X
Other carbohydrates, calculated from crude fat	X	X	X	X
Other carbohydrates, calculated from crude fat with hydrolysis	X	X	X	X
Non-starch polysaccharides	X	X	X	X
Starch, Ewers method	X	X	X	X
Starch, amyloglucocidase	X	X	X	X
Sugar	X	X	X	X
Neutral detergent fibre	X	X	X	X
Acid detergent fibre	X	X	X	X
Acid detergent lignin	X	X	X	X
Net energy for milk production	X			
Nnet energy for meat production	X			
Net energy (pigs)		X		
Metabolisable energy broilers				X
Metabolisable energy layers			X	
Digestible lysine, poultry			X	X
Digestible methionine, poultry			X	X
Digestible cysteine, poultry			X	X
Digestible methionine and cysteine, poultry			X	X
Digestible threonine, poultry			X	X
Digestible tryptophane, poultry			X	X
Digestible isoleucine, poultry			X	X

Cont.

TABLE 2: EXTENDED LIST OF FEED CHARACTERISTICS FOR DIFFERENT LIVESTOCK SPECIES (*CONT.)*

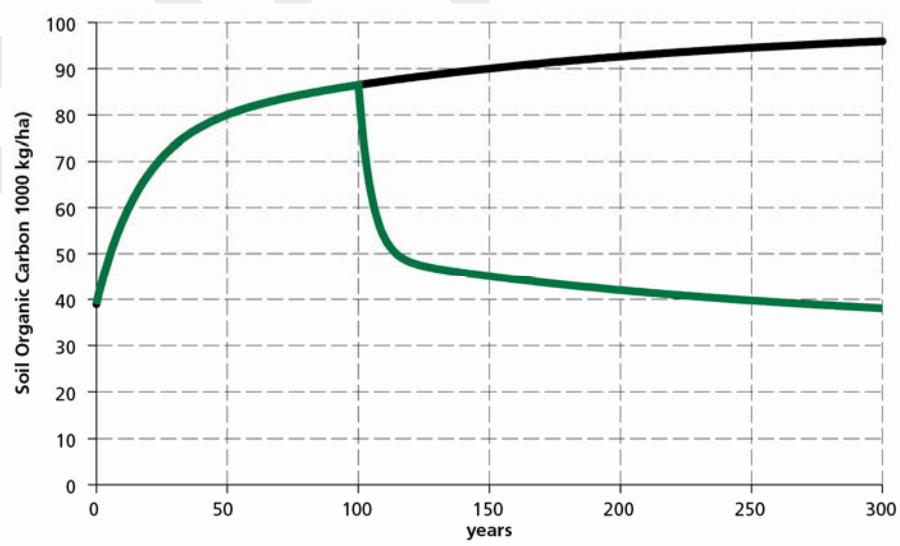
Name English	Ruminants	Pigs	layers	Broilers
Digestible valine, poultry			X	X
Standardised intestine digestible lysine, pigs		X		
Standardised intestine digestible methionine pigs		X		
Standardised intestine digestible cysteine, pigs		X		
Standardised intestine digestible methionine and cysteine, pigs		X		
Standardised intestine digestible threonine, pigs		X		
Standardised intestine digestible tryptophane, pigs		X		
Standardised intestine digestible isoleucine, pigs		X		
Standardised intestine digestible valine, pigs		X		
Lysine	X	X	X	X
Methionine	X	X	X	X
Cysteine		X	X	X
Threonine		X	X	X
Tryptophane		X	X	X
Isoleucine		X	X	X
Valine		X	X	X
Digestibility coefficient crude protein, ruminants	X			
Digestibility coefficient crude fat, ruminants	X			
Digestibility coefficient crude fibre, ruminants	X			
Digestibility coefficient other carbohydrates, ruminants	X			
Digestibility coefficient organic matter, ruminants	X			
Digestibility coefficient crude protein, pigs		X		
Digestibility coefficient crude fat, pigs		X		
Digestibility coefficient crude fibre, pigs		X		
Digestibility coefficient other carbohydrates, pigs		X		
Digestibility coefficient organic matter, pigs		X		
Digestibility coefficient non starch polysaccharides, pigs		X		
Digestibility coefficient crude protein, broilers				X
Digestibility coefficient crude fat, broilers				X
Digestibility coefficient other carbohydrates, broilers				X
Digestibility coefficient crude protein, layers			X	
Digestibility coefficient crude fat, layers			X	
Digestibility coefficient other carbohydrates,layers			X	

Appendix 3: Land use emissions

Secondary data on land use emissions shall be collected from region-specific databases. The example for European temperate conditions is described in detail in this Annex.

Carbon stocks change in relation 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 considerable debate as to whether carbon sequestration tends to reach an equilibrium (Conant et al., 2005) or whether this is an ongoing (Soussana et al., 2007, 2009). According to the equilibrium theory, in the long run the carbon sequestration rate will level off (Figure 1); the other approach posits that the carbon sequestration rate will remain at a more or less constant level. Model calculations show that it takes many years before an equilibrium is reached. Vellinga et al. (2004) calculated sequestration rates of 40 kg C per ha of 200-year old grasslands. 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 this type of research and therefore should be considered the preferred method.

FIGURE 1: THE AMOUNT OF SOIL ORGANIC CARBON UNDER GRASSLAND (TOP LINE), ARABLE LAND (BOTTOM LINE)



Note: Arable land can be considered as such a 100-year life as grassland. After 200 years of grassland, carbon sequestration still stands at 40 kg C per ha per year. After arable land as had a 200 year life, emission of soil carbon is still 30 kg C per ha per year. These calculations are based on Vellinga et al. (2004).

Similar differences in approach can be found under arable conditions. As a result of cultivation carbon stocks tend to decrease. The decrease rate, however, is affected strongly by the return of crop residues to the field, the application of organic manure and the degree of tillage intensity. No-tillage systems lead to increased soil organic carbon contents. Sukkel (*personal communicationI*) found literature indicating significant and long-lasting depletion of soil organic carbon on arable land. 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 ongoing sequestration on grassland, when it comes to carbon losses under arable land, they accept the equilibrium method. The equilibrium method is also endorsed 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 mature (200 years) arable land. Sukkel (*personal communication*) did not find any differences in carbon loss or sequestration among European countries.

Another point of debate is the reference level. Leip et al. (2010) use natural grassland vegetation as the reference level. Because intensively managed grassland has a higher carbon sequestration rate, land use emissions on such areas are negative. Following this same approach, arable land, without sequestration and without net loss of soil carbon has a (calculated) emission of CO_2, which can be interpreted as a “not realized sequestration”.. In contrast, one can propose two reasons for using current agricultural land as a reference level instead of the natural vegetation. First, natural grassland vegetation is difficult to quantify given the pervasive and historical of human activities and its impact on vegetation. Second, the use of natural vegetation as a reference calculates foregone sequestration as a carbon loss, that is, as an emission into the atmosphere. Instead, emissions by land use can be calculated on the basis of a long time equilibrium and with current land use as the reference point.

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 crop type. In the event of developing defaults at a national level, it will prove impossible to make such detailed calculations. For grassland, a carbon sequestration rate of 114 kg per ha per year is used for permanent pastures without grassland renovation, with an assumed minimum and maximum rates of between 0 and 228 kg per ha per year, respectively. In the case of grassland renovation, the sequestration rates are lower (Table 3). And this is especially the case when grassland renovation is combined with two years of in-between maize cropping. In those cases, a similar range of 100 percent above and below the value can be applied.

TABLE 3: CHANGES IN CARBON STOCKS FOR DIFFERENT SITUATIONS OF LONG TERM GRASSLAND MANAGEMENT

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

Source: Calculations based on Vellinga and Hoving (2011)

In addition to the changes in carbon stocks, grassland renovation and ploughing grassland for maize also affect the emissions of nitrous oxide during the period of sward destruction. For grassland renovation, the period of sward destruction is short, but for maize this period lasts two years. The nitrous oxide emissions are shown in Table 4.

TABLE 4: LOSSES OF N, NITROUS OXIDE EMISSIONS EXPRESSED AS N_2O-N AND CO_2 EQUIVALENTS PER HECTARE PER YEAR

	N-loss due to ploughing (kg/ha)	Total emissions of N_2O-N (kg/ha)	Total emissions of CO_2eq (kg/ha)	Annual emissions N_2O-N (kg/ha/year)	Annual emissions CO_2eq (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

Note: Emissions from changing carbon stocks, including grassland renovation: (all expressed in kg/ha.year) (Vellinga and Hoving, 2011)

Carbon stocks (long-term average)

dC stocks = 114 * No renovation + 47 * Renovation – 99 * Maizegrass

CO_2 emission = dC stocks * 44/12

Nitrous oxide (at ploughing, averaged over whole period)

N_2O cultivation = (0.38 * Renovation + 1.90 * Maizegrass) * 44/28

CO_2eq. cultivation = N_2O emissions * 298

No renovation, renovation and maizegrass can be treated as Boolean variables.

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. Extremely high rates in the range of 600 to more than 1000 kg can be seen instead in situations involving recent land use change. The fluctuations of soil organic carbon due to ley-arable rotation schemes are considered to be short term carbon changes and are taken into account.

References

Conant, R.T., Paustian, K., Del Grosso, S.J., Parton, W.J.2005. Nitrogen pools and fluxes in grassland soils sequestering carbon. *Nutrient Cycling in Agroecosystems* 71, 239-248.

Leip, A., Weiss, F., Wassenaar, T., Perez, I., Fellmann, T., Loudjani, P., Tubiello, F., Grandgirard, D., Monni, S., Biala, K. 2010. Evaluation of the livestock sector's contribution to the EU greenhouse gas emissions (GGELS) –*Final report*. European Commission, Joint Research Centre.

Reijneveld, A., van Wensem, J., Oenema, O. 2009. Soil organic carbon contents of agricultural land in the Netherlands between 1984 and 2004. *Geoderma* 152 (2009) 231–238.

Soussana, J.F., Allard, V., Pilegaard, K., Ambus, P., Amman, C., Campbell, C., Ceschia, E., Clifton-Brown, J., Czobel, S., Domingues, R., Flechard, C., Fuhrer, J., Hensen, A., Horvath, L., Jones, M., Kasper, G., Martin, C., Nagy, Z., Neftel, A., Raschi, A., Baronti, S., Rees, R.M., Skiba, U., Stefani, P., Manca, G., Sutton, M., Tubaf, Z., Valentini, R. 2007. Full accounting of the greenhouse gas (CO2, N2O, CH4) budget of nine European grassland sites. *Agriculture Ecosystems & Environment* 121, 121-134.

Soussana, J.F., Tallec, T., Blanfort, V. 2009 : Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. *Animal* 4(3): 334-350.

Vellinga, T.V., Van den Pol-Van Dasselaar, A., Kuikman, P.J. 2004. The impact of grassland ploughing on CO2 and N2O emissions in the Netherlands. *Nutrient Cycling in Agroecosystems*. 70, 33-45.

Vellinga and Hoving. 2011 .Maize silage for dairy cows: mitigation of methane emissions can be offset by land use change. *Nutrient Cycling in Agroecosystems* (2011) 89:413–426.

Appendix 4: Oxidation of peat

The most recent reference for oxidation of peat is the report:

Joosten, H. (2009*) The Global Peatland CO2 Picture. Peatland status and emissions in all countries of the world Report Wetlands International, Ede, 2009.*

The section about the emission factors for peat land is derived from that report:

The emissions discussed here are only those deriving from the biological oxidation of peat. Emissions combustion fire are not included. Default emission factors for CO2 are derived from Couwenberg (2009) or based on interpolations and educated estimates. Only emissions from drained peatlands are included, CO_2 and CH_4 fluxes in pristine peatlands are – as per the UNFCCC philosophy - not addressed.

Drained peatlands emit only minor amounts of CH_4, whereas the anthropogenic CH_4 emissions in rewetted peatlands are assumed to be out by reduced CO_2 emissions. In rice fields cultivated on peat soil, CH_4 emissions are derived largely from young plant material, while the role of the peat soil as a substrate for CH_4 production can be expected to be limited given the recalcitrance of tropical peat (Couwenberg et al., 2009). And although on the other hand emissions of N_2O may be substantial, the latter are not taken into account because of the lack of good proxies for the rather erratic fluxes that depend largely on the amount and timing of fertilizer application.

TABLE 5: DEFAULT VALUES USED FOR CO_2 EMISSIONS FROM DRAINED PEAT SOILS (IN T CO_2/HA/YEAR)

	Forest land/ Agroforestry	Cropland	Grassland	Extraction sites
Tropical	**40**	**40**	**40**	**30**
Subtropical	*30*	*35*	*30*	*25*
Temperate	*20*	*25*	*20*	*15*
Boreal	**7**	**25**	**10**	**10**

Note: The figures in bold are derived from Couwenberg (2009), the italics represent interpolated
* This paper evaluates IPCC approaches to GHG emissions from managed organic (peat) soils and concludes with a summary table comparing IPCC 2006 default values with best estimates as based on the recent literature.

References

Couwenberg J. 2009 *Emission factors for managed peat soils (organic soils, histosols). An analysis of IPCC default values*. Report, 14pp. Wetlands International, Ede.

Joosten, H. 2009 The *Global Peatland CO2 Picture: Peatland status and emissions in all countries of the world* Report Wetlands International, Ede.

Appendix 5: Rice cultivation

Methane is emitted during cultivation of rice. The methodology to calculate methane emissions from rice cultivation are elaborated in the 2006 IPCC Guidelines (IPCC, 2006). For rice cultivation, the Tier 1 approach is recommended.

The IPCC Tier 1 is posited on the formula: CH4-rice = EFch4rice * cultivation period

EF = emission factor, expressed in kg CH4 per day per hectare

Cultivation period = the length of the period from seeding until harvest. In the case of ratoon rice, the first period from seed to seedlings must be factored in.

EFCH4rice = EFc * SFw * SFp * SFo

EFc = basic emission factor

SFw = scaling factor (correction factor) for water regime during cultivation

SFp = scaling factor for water regime in pre-cultivation period

SFo = organic matter amendments

EFc = 1.30 kg CH_4 per hectare per day (range 0.80 – 2.20, normal distribution)

SFw: see Table 5.12 (IPCC, 2006)

It is known that irrigation is a widespread practice in Eastern China. In this case, the aggregated value of 0.78 for the SFw factor would appear to be the most appropriate. . In the case of the SFp factor, an aggregated value of 1.22 is considered suitable for the average situation.

SFp: see Table 5.13 (IPCC, 2006)

SFo: see Equation 5.3 (IPCC, 2006)

SFo = scaling factor for both type and amount of organic amendment applied

ROA*i* = application rate of organic amendment *i*, in dry weight for straw and fresh weight for others, tonne ha^{-1}

CFOA*i* = conversion factor for organic amendment *i* (in terms of its relative effect with respect to straw applied shortly before cultivation) as shown in Table 5.14 (IPCC, 2006).

This formula will be modified in order to incorporate rice straw.

SFo = (1 + (CRrice/1000 * 0.29 + Nmanure/Ncontentmanure * 0.14))$^{0.59}$

The Ncontentmanure is expressed in g/kg (or kg/ton). The value is set at 4 kg/ton. It is assumed that rice straw is incorporated more than 30 days before a new crop is planted.

Table 6 shows the value of the factor SFo in the case of the conversion factor = 0.29 where the yield of the crop residue ranges from 1000 to 6000 kg of dry matter per hectare.

TABLE 6: THE VALUE OF THE FACTOR SF_0, IN THE CASE OF THE VALUE OF THE CONVERSION FACTOR OF 0.29 AND A CROP RESIDUE YIELD IN THE RANGE OF 1000 TO 6000 KG PER HECTARE

0.29	1000	1.162112
0.29	2000	1.309808
0.29	3000	1.446727
0.29	4000	1.575171
0.29	5000	1.696711
0.29	6000	1.812478

References

IPCC. (2006). *IPCC guidelines for national greenhouse gas inventories*. Prepared by the national greenhouse gas inventories programme. IGES, Japan.

Appendix 6: Anaerobic storage

In palm oil production, the palm oil mill effluent (POME) is a wastewater rich in organic material that often is anaerobically treated in ponds. In such cases methane is released. The most direct and reliable study of this phenomenon is an extensive series of direct measurements by Yacob (2006), giving an average figure of 6.5 kg of methane per ton of input of FFB.

References

Yacob, S. et al. 2006. Baseline study of methane emission from anaerobic ponds. *Science of The Total Environment*, Volume 366, Issue 1, Pages 187-196, 2006.

Appendix 7: Transport distances

1. Reference units

The reference unit for transport is directly related to those units that are used as outputs of crop production, processing, and feed mill, per 1000 kg of product.

Transport is considered to germane to every step in the feed production chain. It can be transport of crop products from arable farm directly to the livestock farm, or going further on to a facility for industrial processing. For example, the co products from processing are transported to the feed mill.. Every instance of transport is defined by (a) the distance between the point of departure (D) and the point of arrival (A); and (b) the transport modalities used, whether one or more. The final unit used to calculate transport is the transport of 1000 kg of product over 1 kilometre with transport modalities expressed as T_1 - T_x (ton-km). A third defining factor is related to the transport efficiency, which includes loading of the means of transport, quality of roads, and so on.

The GHG emissions from transport were calculated by applying secondary data on the use of a transport modality, expressed as g CO_2-equivalents per ton-km.

2. System boundary

International databases such as Ecoinvent distinguish between “operational” emissions (emissions during the period of transportation itself) and emissions from constructing infrastructure, buildings and the various transport modalities (trains, boats etc.). The latter emissions are called “production” emissions in this document.

Ecoinvent therefore provides two emission factors:

- “Operational” emission factor (kg CO_2/km)
- “Operational + production” emission factor (kg CO_2/ton-km)

The difference between “operational” and “production” emissions can differ by 15 percent (Hischier et al. 2009; Van Kernebeek and Splinter, 2011).

A database shall be used that supplies the emission factors for a number of types of trucks, trains, ships and airplanes. These shall be based on regional transport characteristics.

3. Transport distances and modalities

Place of departure and of arrival

In case-specific studies, the places of departure and arrival of agricultural commodities can be known in detail. In more general studies where no exact locations can be defined, a database with default values shall be used. For all transport modalities, the place of departure and arrival will be chosen through a standardised approach based on the chain description of the particular product.

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

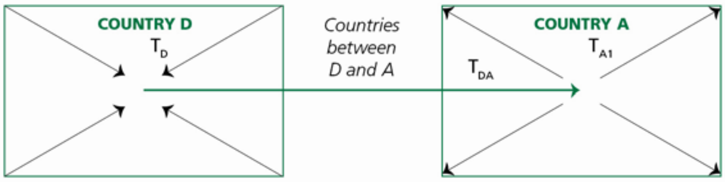
- Feed materials used at arrival point A, but grown in other countries, can be processed in the country where the crop or basic animal product is produced, but can also be processed in the country of the arrival point.
- When a product is transported to the next step in the chain within the same country, the distance shall be calculated from 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 ship after processing, the location of processing is considered to be the largest port in a country. In case of transport after processing by inland vessels, the largest inland port is chosen as the location for processing.
- Transport of end-products within the Netherlands is based on a standardized inland transport distance.

a) Transport from country D(eparture) to A(rrival) by truck

Situation 1: Crop and processing in the same country, feed mill and farm in A.

- 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. In such a case, the inland distance for transport from field to processing plant is used for calculations.
- When the co product is transported from country D to A, we go from one midpoint to the other. This is assumed to be the average distance between locations in both countries. No extra inland transport in country D or A is incorporated into calculations.
- Inland transport in country A is treated in a similar fashion to the inland transport in country D, using the average distance for inland transport in A.

FIGURE 1: TRANSPORT SCHEME FOR SITUATION 1 AND 2 WITH INTERNATIONAL TRUCK TRANSPORT



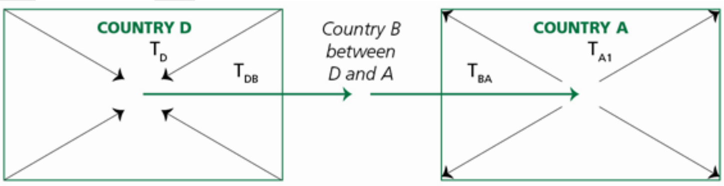
Situation 2: Crop in country D, processing, feed mill and farm in A.

- When the crop is transported from country D to A, we go from one midpoint to the other. This is assumed to be the average distance between locations in both countries. No extra inland transport in country D or A is incorporated.
- In the case of inland transport in country A from processing to feed mill and from feed mill to farm calculation is done by using the average distance for inland transport in A: T_{A1}.

Situation 3: Crop in D, processing in B, feed mill and farm in A

- When the crop is transported from country A to B by truck, we go from 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 included.
- Transport from country B (processing) to A (feed mill) goes from midpoint to midpoint.
- Inland transport in country A from feed mill to farm is calculated by using the average distance for inland transport in A: T_{A1}.

FIGURE 2: TRANSPORT SCHEME FOR SITUATION 3 WITH INTERNATIONAL TRUCK TRANSPORT



The approach for between-country transport by truck is summarized in Table 7.

TABLE 7: TRANSPORT DISTANCES FROM COUNTRY D TO A IN CASE OF TRUCK TRANSPORT

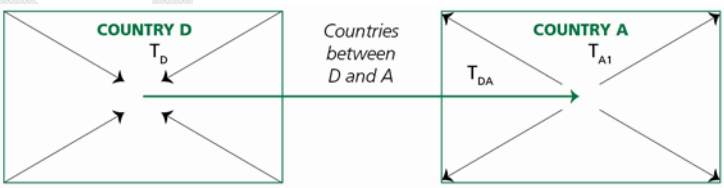
Production phase	**Country/*distance***		
Crop	D	D	D
transport	T_D	T_{DA}	T_{DB}
Processing	D	A	B
transport	T_{DA}	T_{A1}	T_{BA}
Feed mill	A	A	A
transport	T_{A1}	T_{A1}	T_{A1}
Farm	A	A	A

b) Transport from country D to A by inland ship

Situation 1: Crop and processing in the same country, feed mill and farm in A.

- The crop is transported from the field to the processing plant. Neither the distance between the processing plant and the crop location, nor the number of processing plants is known. For calculations use the inland distance for transport from field to processing plant.
- After processing, the co-product is transported from country D to A, from one midpoint to the other. This is assumed to be the average distance between locations in both countries. No extra inland transport in A is factored in.
- Inland transport in country A is treated similarly to the inland transport in country D, using the average distance for inland transport in A.

FIGURE 3: TRANSPORT SCHEME FOR SITUATION 1 AND 2 WITH INTERNATIONAL INLAND SHIP TRANSPORT



Situation 2: Crop in country D, processing , feed mill and farm in A.

- When the crop is transported from country D to A, the crop is transported to the inland port, assuming a distance of T_D. From there it is transported by ship. No extra inland transport in country D or A is incorporated.

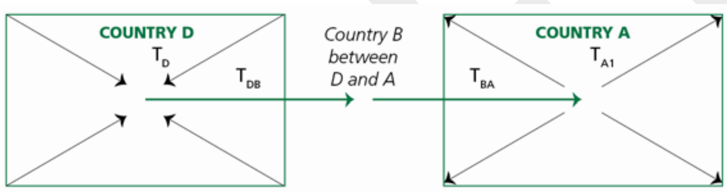
- Inland transport in country A from processing to feed mill and from feed mill to farm is calculated by using the average distance for inland transport in A: T_{A1}.

Situation 3: Crop in A, processing in B, feed mill and farm in D

Situation 3A: Transport from D to B by truck, B to A by inland ship

- The crop is transported from country D to B for processing, midpoint to midpoint by truck, with distance =T_{DB}.
- After processing, the product is shipped from country B midpoint to A midpoint by inland ship, with distance = T_{BA}.
- Inland transport in country A from feed mill to farm is calculated by using the average distance for inland transport in A: T_{A1}.

FIGURE 4: TRANSPORT SCHEME FOR SITUATION 3A AND 3B WITH INTERNATIONAL INLAND SHIP TRANSPORT



Situation 3B: Transport from D to B and from B to A by inland ship

- The crop is transported to an inland port in country D and then shipped to country B. For transport to the inland port the average inland distance is used (T_D). Transport from D to B is the standard distance =T_{DB}. Processing takes place at the inland port.. Consequently, there is no extra transport in country B.
- As a result, transport from country B to A by inland ship is from midpoint to midpoint, distance = T_{BA}.
- Inland transport in country A from feed mill to farm is calculated by using the average distance for inland transport in A: T_{A1}.

The approach for between country transport by inland ship is summarized in Table 8.

TABLE 8: TRANSPORT DISTANCES FROM COUNTRY A TO NL WITH TRANSPORT TO NL BY INLAND WATERWAY.

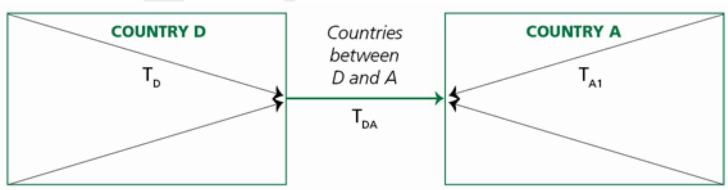
Production phase	**Country/*distance***			
Crop	D	D	D	D
transport	T_D	$T_D + T_{DA}$	T_{DB}	$T_D + T_{DB}$
Processing	D	A	B	B
transport	T_{DA}	T_{A1}	T_{BA}	T_{BA}
Feed mill	A	A	A	A
transport	T_{A1}	T_{A1}	T_{A1}	T_{A1}
Farm	A	A	A	A

c) Transport from country D to A by sea

Situation 1: Crop and processing in the same country, feed mill and farm in A.

- 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 D to A, from one seaport to the other. Inland transport in A is incorporated.
- Inland transport in country A is treated similarly to the inland transport in country D, using the average distance for inland transport in A.

FIGURE 5: TRANSPORT SCHEME FOR SITUATION 1 AND 2 WITH INTERNATIONAL SEA SHIP TRANSPORT



Situation 2: Crop in country D, processing , feed mill and farm in A.

- When the crop is transported from country D to A, it is transported to the seaport, assuming a distance of T_D. From there it is transported by ship. No inland transport in country D is incorporated. It is assumed that the crop is processed close to the seaport.

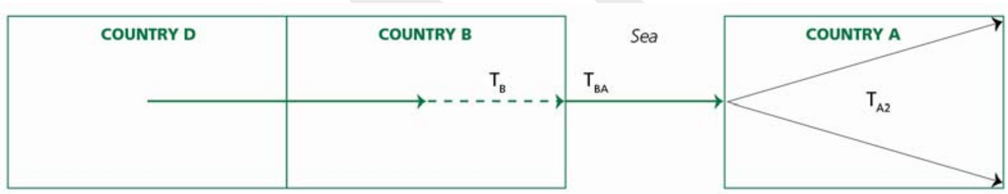
- Inland transport in country A from processing to feed mill is based on inland ship and truck, for 80 percent and 20 percent respectively. For that calculation T_{A2} is used. Transport from feed mill to farm is calculated by using the average distance for inland transport in A: T_{A1}.

Situation 3: Crop in D, processing in B, feed mill and farm in A

Situation 3A: Transport D to B by truck, B to A by sea

- Transport from country D to country B by truck goes from midpoint to midpoint, distance = T_{DB}.
- Transport from country B to A goes from midpoint to port by truck (or inland ship), which is D_B, followed by transport from B to A by sea ship, which is T_{BA}. Once arrived in A it is immediately transported to the feed mill, which is T_{A2}.
- Transport from feed mill to farm is calculated by using the average distance for inland transport in A: T_{A1}.

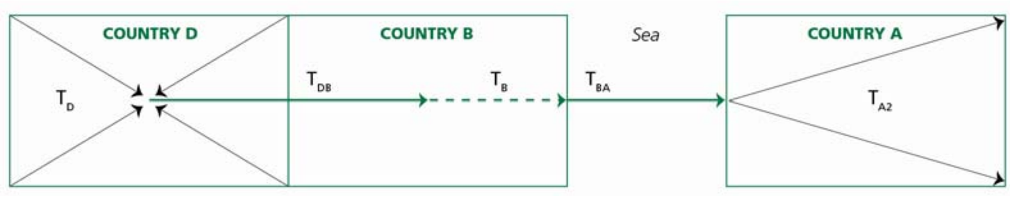
FIGURE 6: TRANSPORT SCHEME FOR SITUATION 3A WITH INTERNATIONAL SEA SHIP TRANSPORT



Situation 3B: Transport D to B by inland ship, B to A by sea ship

- Transport from country D to country B by truck goes from inland port to inland port, which is assumed to be the same as the midpoint distance, D_D. From the inland port the midpoint to midpoint distance between countries D and B is used = T_{DB}.
- Transport from country B to A goes from midpoint to port by truck (or inland ship), to the seaport, which is D_B, followed by transport from B to A by sea ship, which is T_{BA}. In A it is immediately transported to the feed mill, which is T_{A2}.
- Transport from feed mill to farm is calculated by using the average distance for inland transport in A: T_{A1}.

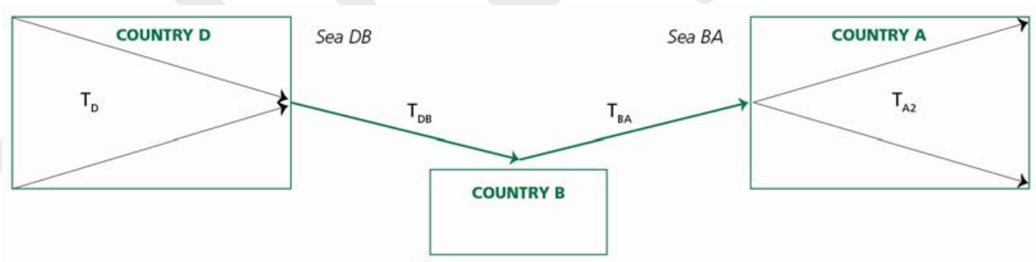
FIGURE 7: TRANSPORT SCHEME FOR SITUATION 3B WITH INTERNATIONAL SEA SHIP TRANSPORT



Situation 3C: Transport D to B by sea ship, B to A by sea

- When the crop is transported from country D to B, the crop is transported to the seaport, assuming a distance of D_D. From there it is transported by 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 A is port to port. From the seaport it goes to the feed mill via inland ship and truck, 80 percent and 20 percent respectively. For that calculation T_{A2} is used.
- Transport from feed mill to farm is calculated by using the average distance for inland transport in A: T_{A1}.

FIGURE 8: TRANSPORT SCHEME FOR SITUATION 3C WITH INTERNATIONAL SEA SHIP TRANSPORT



The approach for between-country transport by sea ship is summarized in Table 9.

TABLE 9: TRANSPORT DISTANCES FROM COUNTRY D TO A IN CASE OF TRANSPORT TO A BY SEA SHIP.

Production phase	**Country/*distance***				
Crop	D	D	D	D	D
transport	T_D	$T_D + TT_A$	T_{DB}	$T_D + T_{DB}$	$T_D + T_{DB}$
Processing	D	A	B	B	B
transport	$T_{DA} + T_{A2}$	T_{A2}	$T_{BA} + T_{A2}$	$T_{BA} + T_{A2}$	$T_{BA} + T_{A2}$
Feed mill	A	A	A	A	A
transport	T_{A1}	T_{A1}	T_{A1}	T_{A1}	T_{A1}
Farm	A	A	A	A	A

The basic method was to define the geographic midpoint of a country. This can be done by using the Geographic Midpoint Calculator (http://www.geomidpoint.com/). However, more detailed information of cropping areas was preferred over the geographic midpoint approach. Information regarding the main cropping areas was based on a literature search and country statistics.

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 significant effect on the transport distance.

4. 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 shall 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 where trains are used as a transport modality, than the availability of a distance calculator should be ascertained.

- **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/)., The specific starting port and destination port are filled out on Portworld's online distance calculator and the distance (in kilometres) is provided. When Portworld does not provide a port for any given country, then the transport distance can be computer by choosing another port is chosen, (preferably the capital of the country) and using the online distance calculator of Sea Rates (http://www.searates.com/reference/portdistance/?fcity1=33937&fcity2=20197&speed=14&c

code=328). What this calculator does is to convert the distance in nautical miles was into kilometres using a 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 in order toto imitate the inland vessel waterways. A map of European inland vessel waterways can be found at Bureau Voorlichting Binnenvaart (2011).
- Distances travelled by ship in **short sea voyages** can be computed, again, by using Portworld's online tool (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

Inlands vessels can carry a volume of 500–5000 tons, depending on the state of the technology and of the size of the waterways. The carrying capacity of sea ships generally used for shipping bulk cargo (wheat and soybean) overseas ranges between 3.000 and 300.000 tons (Bulk carrier guide, 2010). Wheat and soy from South America are usually carried by Panamax vessels, the carrying capacities of which can vary widely. Dry bulk tankers range in type from Handysize vessels with a carrying capacity of from 20.000 to 35.000 tons and which have access to a large number of ports, Panamax vessels with a carrying capacity of 50.000 – 80.000 tons and Cape size vessels with a carrying capacity of 100.000 to 300.000 tons that can only access only the largest seaports and cannot pass through the Panama Canal (Bradley et al., 2009).

5. The transport matrix

A transport matrix can be constructed where transport within countries and between countries is defined and where all relevant modalities have been identified. When products are transported, e.g. from Australia to the Netherlands, sea transport plays an important role. The transport in Australia serves 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 has already been processed, transport in the Netherlands refers 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 10: A SELECTION OF THE TRANSPORT MATRIX FOR THE USE IN THE CALCULATION TOOL

from LandD	Australia	Belgium	Brazil	Canada	the Netherlands
to LandA	the Netherlands	the Netherlands	the Netherlands	the Netherlands	the Netherlands
LorryD	400	212	1077	2000	93
TrainD	100				
SeaShip	19668		9684	5124	-
InlandshipD			0		
Airplane					
LorryA	19		19	19	
TrainA					
InlandshipA	108		108	108	

Note: The figures ….D and …A indicate the country of departure and the country of arrival.

References

Bradley, D., Diesenreiter, F., Wild, M., Tromborg, E. 2009. World Biofuel Maritime Shipping Study.

Bulkcarrierguide, 2010. http://bulkcarrierguide.com/U.S. Soybean Export Council, 2006. International Buyer's Guide. Chapter 4. Transporting U.S. Soybeans to Export Markets. http://ussec.org/ussoy/buyersguide.html.

Hischier, R., Althaus H.-J., Bauer, Chr., Doka, G., Frischknecht R., Jungbluth N., Margni M., Nemecek, T., Simons A., Spielmann M. 2009 *Documentation of changes implemented in Ecoinvent Data* v2.1. Final report ecoinvent data v2.1. Volume: 16. Swiss Centre for LCI. Dübendorf. CH.

Van Kernebeek, H.R.J., Splinter, G. 2011. Ontwikkeling van een rekenmethodiek voor broeikasgasemissies tijdens transport. *Toepassing binnen het project Venlog*. LEI nota 11-004.

Appendix 8: Case studies for feed LCA

1. Fodder production and marketing chains in Kenya: A Napier and Rhodes grass case study
2. The food-feed crops production and processing in Kenya. A wheat and maize case study
3. The concentrate feed value chain in Uganda or Kenya
4. Animal feed supply chain for the poultry sector – A North America case study

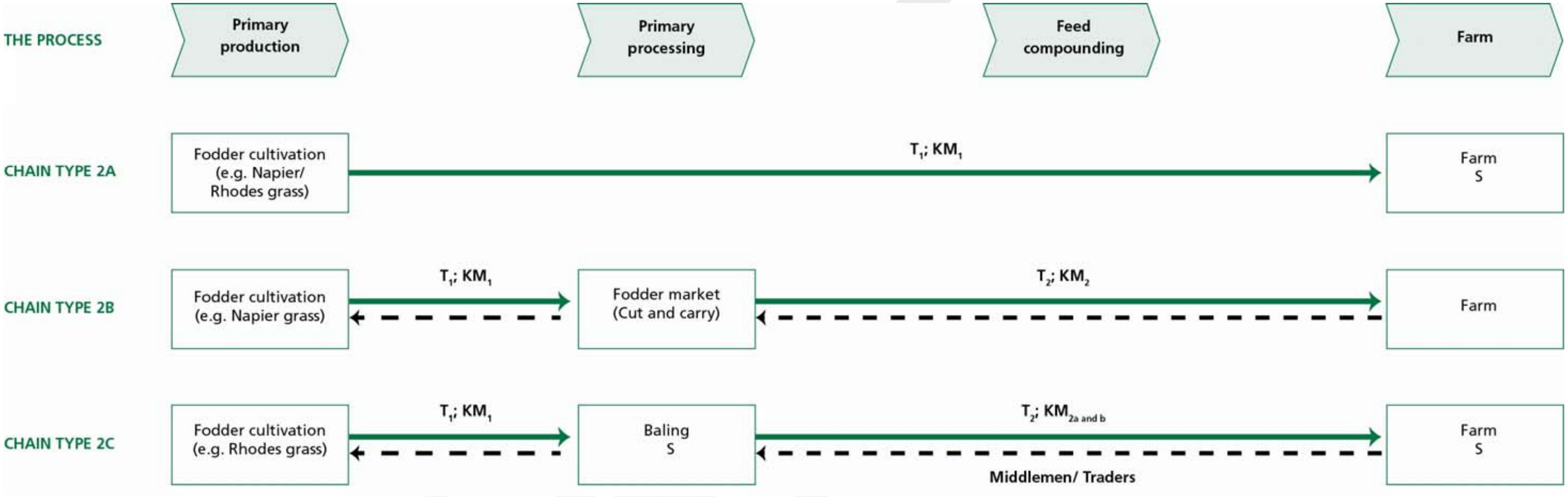

THE PROCESS
Primary production
Primary processing
Feed compounding
Farm
CHAIN TYPE 2A
Fodder cultivation (e.g. Napier/ Rhodes grass)
T_1; KM_1
Farm S
CHAIN TYPE 2B
Fodder cultivation (e.g. Napier grass)
T_1; KM_1
Fodder market (Cut and carry)
T_2; KM_2
Farm
CHAIN TYPE 2C
Fodder cultivation (e.g. Rhodes grass)
T_1; KM_1
Baling S
T_2; $KM_{2a\ and\ b}$
Farm S
Middlemen/ Traders

TABLE 1: DESCRIPTION OF THE FODDER MARKETING CHAIN IN EASTERN AFRICA

Chain type	Description of the fodder marketing chain in Kenya
Chain type 2A:	This chain is common on smallholder farms. Planted fodder (Napier grass (NG) or Rhodes grass (RG) is cultivated, harvested and transported for feeding to livestock which often is confined in 'zero grazing' units or tethered in homesteads. Fodder is harvested manually and transported (T_1) to the farm manually (carried by hand, wheelbarrow, or carted by donkey etc.). The distance (km_1) on farms is from100 to 500m. In rare cases, where farmers grow fodder on owned or rented farms far from where they live, distances can increase to up to 1 to 2 km. Fodder is usually processed directly on the farm either manually or by electric or diesel powered choppers or pulverisers. Storage (S) on farms lasts from to 3 days. About 90 percent of NG and 10 percent of RG passes along this chain.
Chain type 2B	In this chain, planted fodder and grass are cultivated and the harvested for sale often by farmers who have excess fodder or those who do not own livestock. Fodder is either be sold *in situ* and then harvested by buyers as the need arises or transported to fodder markets in town centres or by the road side. Harvesting is usually manual. No processing is done at this stage. The distances (km_2) to and from fodder markets range from 1 to 5 km. Buyers and sellers transport fodder using bicycles, motor cycles or 7 tonne pickup tracks depending on the amounts involved. Processing and storage on farm is as in chin type 2A. About 10 percent of NG passes through this chain
Chain type 2C	This chain commonly involves medium to large farms which cultivate grass fodder (acres) mainly for sale. It involves Rhodes grass (RG) only which is harvested and baled on farms. Bales of RG are transported (T_1) from fields for storage on farm – 200-1000m. Bales of RG may be stored – S (1-2 weeks) and sold in batches or directly delivered to buyers. Piece meal sale is two way, buyers (often small scale) come to buy from the farm or sellers deliver to buyers (middlemen or large scale farmers). Small scale farmers buy 100-500 bales and transport up to 15 km, (KM_{2a}) using 5 – 7 tonne tracks. Large-scale farmers or middlemen buy from 1000 to 5000 bales and transport such bales up to 350 km away using 14-ton trucks. Storage on farms (S) often lasts from 1 to 3 months. Some farmers will chop or pulverize baled grass before feeding or for compounding homemade rations. .About 90 percent of RG passes through this chain.

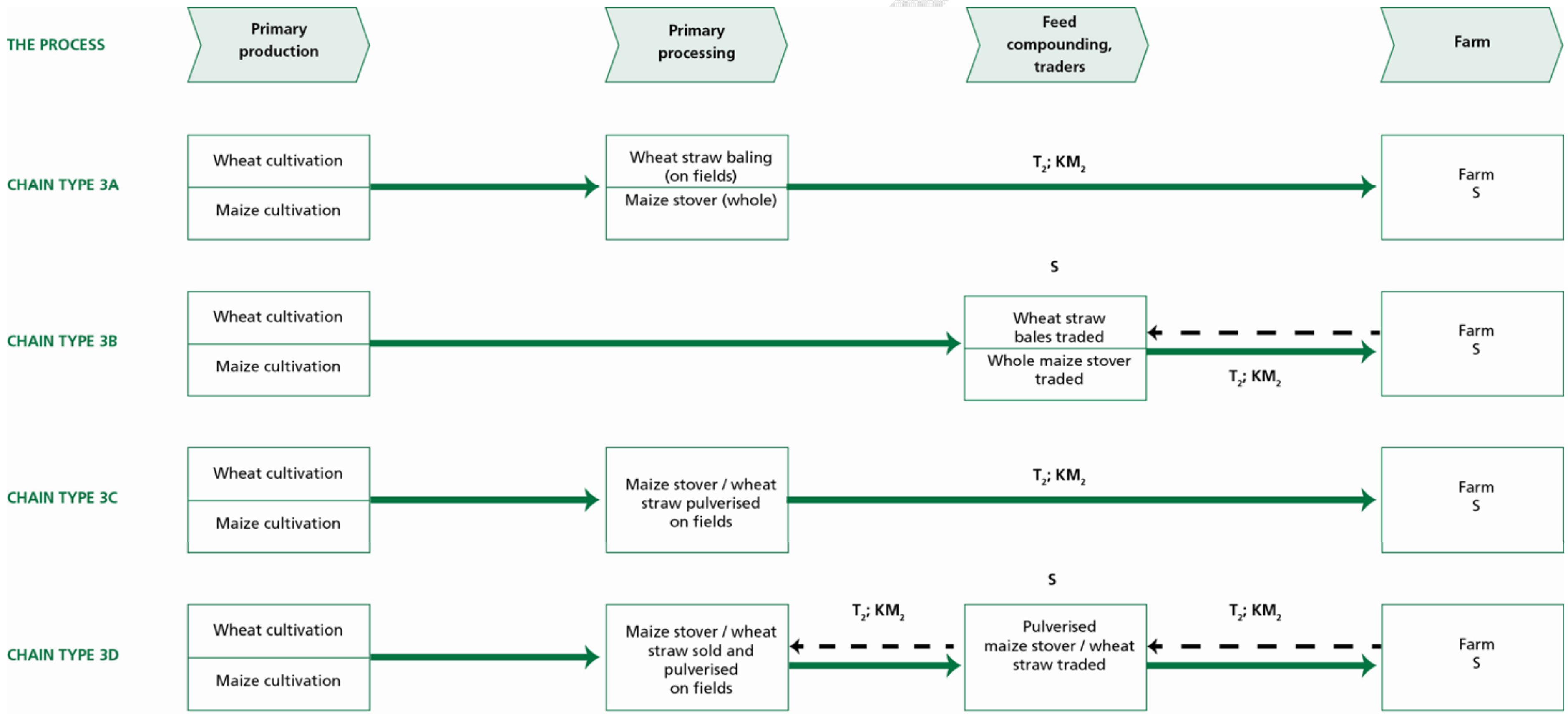

THE PROCESS
Primary production
Primary processing
Feed compounding, traders
Farm
CHAIN TYPE 3A
Wheat cultivation
Maize cultivation
Wheat straw baling (on fields)
Maize stover (whole)
T_2; KM_2
Farm S
S
CHAIN TYPE 3B
Wheat cultivation
Maize cultivation
Wheat straw bales traded
Whole maize stover traded
T_2; KM_2
Farm S
CHAIN TYPE 3C
Wheat cultivation
Maize cultivation
Maize stover / wheat straw pulverised on fields
T_2; KM_2
Farm S
S
CHAIN TYPE 3D
Wheat cultivation
Maize cultivation
Maize stover / wheat straw sold and pulverised on fields
T_2; KM_2
Pulverised maize stover / wheat straw traded
T_2; KM_2
Farm S

TABLE 2: DESCRIPTION OF THE MAIZE STOVER AND WHEAT STRAW SUPPLY CHAINS IN KENYA

Chain type	Description of the fodder marketing chain in Kenya
Chain type 3A:	In these chains wheat and maize, an important food supply in Eastern Africa, are cultivated. The crop by-products, wheat straw (WS) and maize stover (MS, are used as feed on both large and small farms. In this chain wheat straw bales are made on fields, transported (T_1), stored (S) and then used as animal feed on farms. The bales are transported for distances of up to 50 km (Km_1). Maize stover and wheat straw are often processed on farms using motorized choppers or pulverizers. Approximately 60 percent MS and 15 percent WS passes through this chain.
Chain type 3B	In this chain wheat straw bales made on fields are either bought, transported (T_{2a}) and stored (S) by traders for retailing or, alternatively, bales are delivered (T_{2b}) directly to farmers.. The wheat straw bales are transported over distances of from 50 to 250 km (KM_1). Maize stover is often sold and transported (T_3) for distances of up to20km (Km_2) to livestock farmers directly from the fields. Maize stover and wheat straw are often processed on farms using motorized choppers or pulverizers. Approximately 20 percent MS and 70 percent WS passes through this chain.
Chain type 3C	In these chains crop by-products, loose wheat straw and maize stover, are often processed by service providers using motorized choppers or pulverizers and transported (T_1) to farms for storage (S) and subsequently used in feed compounding of homemade rations. The pulverized crop residues are transported from the fields to farms for distances of up to20 km (Km_1). Approximately 10 percent of MS and WS passes through this chain.
Chain type 3D	In these chains the crop by-products, loose wheat straw and maize stover, are sold to traders and processed using motorized choppers or pulverizers and transported (T_1) to trading points for storage (S). Traders transport pulverized crop residues for distances (T_1) of 50 to100 km. Farmers within the trading catchments buy pulverized crop residues and transport it for distances of up to 20 km (T_2) in order to compound homemade feed rations. Approximately 10 percent of MS and 5 percent of WS passes through this chain.

CONCENTRATE FEED PRODUCTION AND SUPPLY CHAINS IN EASTERN AFRICA

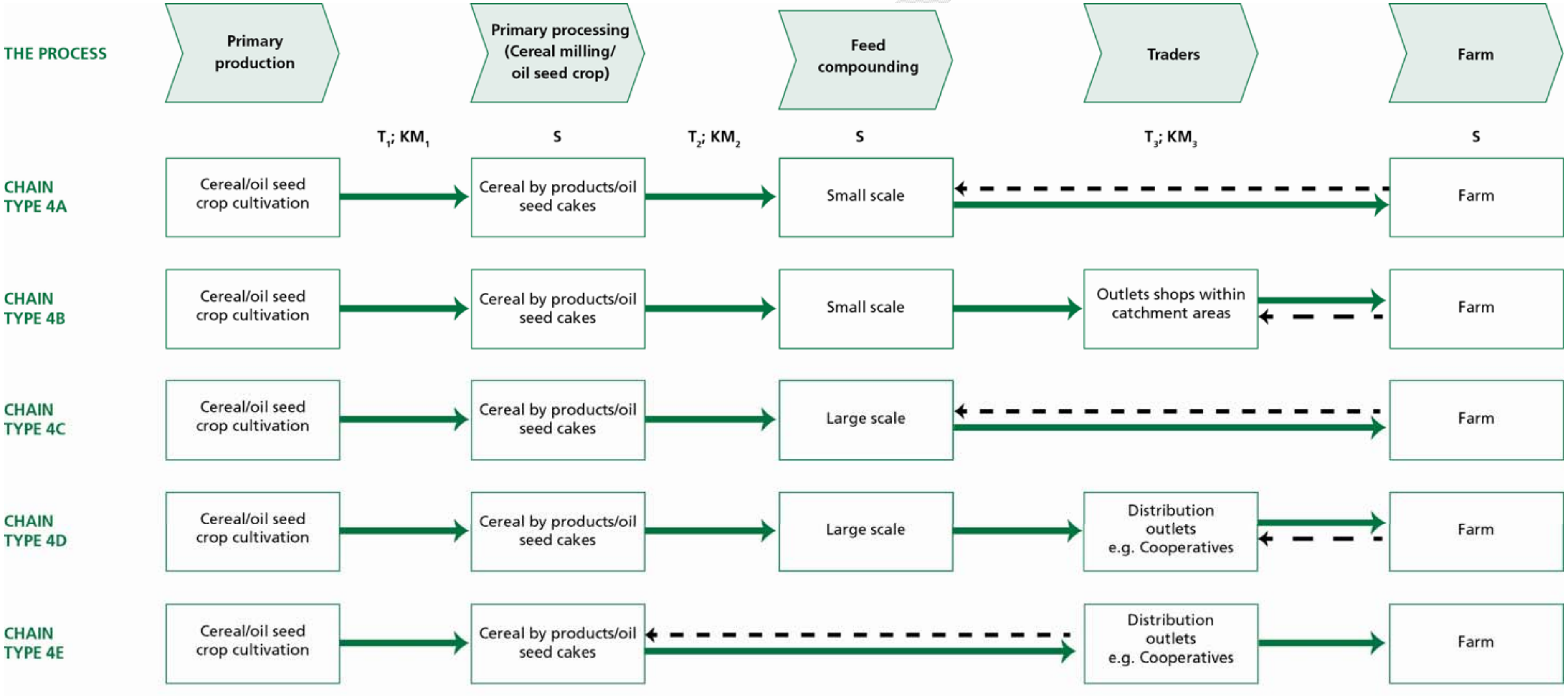


TABLE 3: DESCRIPTION OF THE CONCENTRATE FEED SUPPLY CHAINS IN EAST AFRICA

Chain type	Description of the compounded feed supply chains
Chain type 4A:	These kind of chains are dominated by small scale feed compounders located in both urban and rural areas. Small-scale compounders source and transport (T_1) cereal by-products such as oilseed cakes from traders, agents or milling and oil extraction companies to the their own premises for storage (S; 7 to 17 days). T_1 ranges from 1 to 20 km using mainly 7-ton trucks.. The processing companies source and transport (T_2) raw materials (cereals and oilseeds) from producers. Raw material are stored (S) for periods of from 7-to 30 days.. T_2 ranges from 50 to 250 km using large, 14-ton trucks. Small scale dealers manually mix and package between 2 and 10 tons of feed per day according to farmers' needs. Farmers place orders and collect (T_3) feeds themselves for storage (S; 7 to 14 days) and use the product on farms. T_3 ranges from 1 to 10 km. Small scale farmers also sell feed ingredients directly to farmers for feeding as 'straights'. Approximately 60 percent of compounded feeds (CF) pass through this chain.
Chain type 4B	About 30 percent of the chain type 4A feed compounders open outlets in rural trading catchment areas in an effort to bring services closer to farmers. All the services described in chain type 4A are offered to farmers. However, T_1 ranges from 1 to 30 km using 7-ton tracks while T_2 remains the same. T_3 ranges from only 1 to 5 km using bicycles or motorcycles. Storages (S) periods remain largely the same.
Chain type 4C	The type 4C supply chain is dominated by feed producers who compound more than 100 tonnes of CF daily. In these chains raw materials are sourced from traders and transported (T_2) to processing plants often located in urban areas. T_2 ranges from 100.to 300 km using 10- to14-ton trucks. Traders obtain raw materials from producers or importers and transport (T_1) them for storage in go-downs in urban areas. T_1 ranges from 50 to 150 km using 10- to 14-ton tracks. Compounded feeds are delivered to large-scale farms upon order. T3 ranges from 50 to 200 km using 7 to 10-ton trucks. Purchases are often done in bulk hence storage periods (S) range from 4 to 8 weeks.-, S2 ranges from 2 to -4 weeks and S3 ranges from 4 to 6 weeks. Approximately 5 percent of CF passes through this chain.
Chain type 4D	This chain is basically the same as chain type 4C except that that feed supply to farms is done through distributors or appointed agents. Distributors supply CF to a range of merchants including e.g. dairy cooperatives, agrovet shops, general stores and so on.. T_1 and T_2 are the same. T_3 ranges from 50 to 100 km using 7- to 10-ton tracks. Approximately 35 percent of CF passes through this chain.
Chain type 4E	This chain involves about 60 percent of feed ingredients (cereals and oilseed cakes) that are fed either as straights or compounded into 'homemade' rations on farms. In these chains feed ingredients are sourced from processors, stored by distributors and supplied to a range of merchants including dairy cooperatives, agrovet shops general shops and so on. The modes of transport and distances T_1 , T_2 and T_3 are the same as in chain type 4D.

ANIMAL FEED SUPPLY CHAIN FOR POULTRY SECTOR – A NORTH AMERICA CASE STUDY

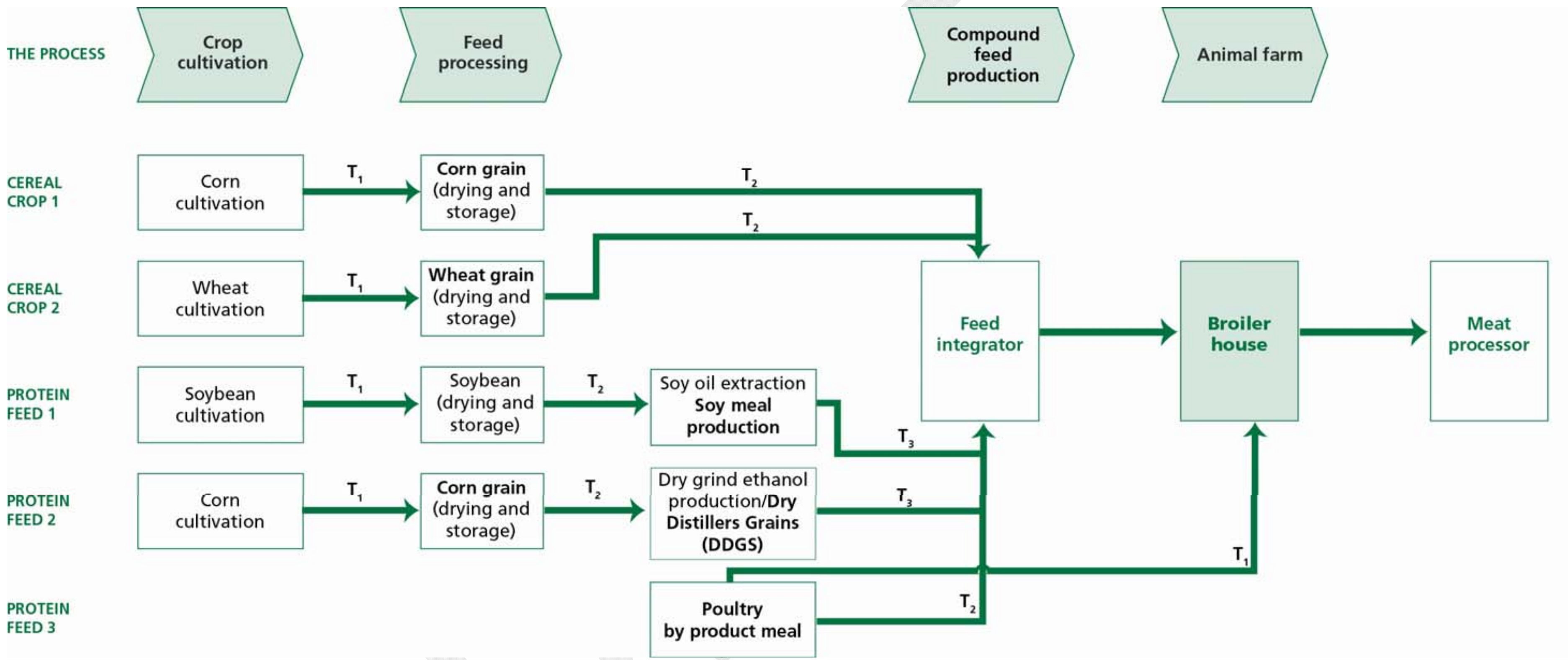


TABLE 4: ANIMAL FEED SUPPLY CHAIN DESCRIPTION FOR US BROILER OPERATIONS

Supply chain type	**Description**
Cereal crop 1 (corn/maize)	Corn cultivation produces corn grain as the main product and stover as a residue/by-product. The residue to grain ratio is ~1:1 and minimum 10-15 percent of residue is left on the field as a soil cover and 50 percent of the remaining residue is harvested and sold as animal feed. After harvesting the grain is typically transported (T1) by medium heavy duty trucks over a distance of 10 miles to the grain elevator, where depending on the incoming corn grain moisture it is dried to 15 percent moisture content before storage in grain elevator. The grain is then transported (T2) by heavy heavy-duty trucks over a distance of 40 miles to the feed integrator, which is located on-site of broiler feeding operation.
Cereal crop 2 (wheat)	Wheat cultivation is similar to corn cultivation, except that the wheat grain to wheat straw (residue/by-product) ratio is ~1.5:1 and minimum 5 percent residue (approx.) is left on the field as a soil cover, and 50 percent of the remaining residue is harvested and sold as animal feed. The transport distances from farm to grain elevator (T1) and elevator to feed integrator (T2) are same as that for corn supply chain, with only difference being the target moisture content before storage, which is 14 percent for wheat grain.
Protein feed 1 (soybean meal)	During soybean cultivation, no residues are removed in order to limit soil erosion. The transport distances from farm to grain elevator (T1) and elevator to oil extraction plant (T2) are same as that for corn and wheat crops. Soybean meal is the only co-product from soybean oil extraction plant. Generally, 48 percent protein content soybean meal are combined with soybean hull and sold as 44 percent soybean meal and transported using heavy heavy-duty trucks (T3) over a distance of 40 miles to the feed integrator.
Protein feed 2 (DDGs)	Dry distillers grains and solubles (DDGS) is a co-product from dry grind corn ethanol production and similar to soybean meal, it is transported using heavy heavy-duty trucks (T3) over a distance of 40 miles from dry grind ethanol plants to the feed integrator.
Protein feed 3 (poultry byproduct meal)	Poultry by-product meal is generated onsite of broiler feeding operation during meat processing. Therefore, transport distances (T1 & T2) are zero, as long as this feed stream meets the requirements of the feed integrator.

**Note:* Residue to grain ratio and harvested residue calculations are based on the parameters in USDA LCA Digital Commons database (www.lcacommons.gov). Transport distances are obtained from US DOE Argonne National Laboratory's GREET software (http://greet.es.anl.gov/).

General description:

The Figure above describes the supply chain for various animal feeds in industrialized feeding systems for Poultry sector (specifically U.S. Broiler industry) in North America. Typical feed composition data (Table 1) is obtained from the latest monthly survey conducted by AGRI STATS of US Broiler operations and represents an average of all types of broiler feed. The total amount of feed and days fed during each growth period are summarized in Table 2.

TABLE 1: US BROILER OPERATIONS – FEED INGREDIENT USAGE VS. PERFORMANCE

	Days to 6 pounds	% Mort	Feed ingredients								
			% Wheat	% CF Meat Products	% DDGS	% SBM	% Syn Lysine	% DL Methionine	% Syn Threonine	% Added Fat	% Corn (by difference)
Wt. Avg. of companies	45.47	3.66	4.31	3.74	5.41	20.95	0.17	0.21	0.05	1.39	63.78

**Note:* CF Meat Products refer to Poultry by-product meal.

Source: AGRI STATS, Nov 2013

TABLE 2: POUNDS OF ANIMAL RATION FED DURING EACH FEEDING PERIOD

Period/feed type	Number of days	Kg fed
Start	16	0.63
Grower	15	1.75
Withdraw	14	2.69
Total	45	5.06

http://www.fao.org/partnerships/leap