Food and Agriculture Organization of the United Nations

VERSION 1

Environmental performance of animal feeds supply chains

Guidelines for assessment

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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 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 growth is projected to continue as a result of sustained demand, especially in developing countries.. Expanding populations, greater purchasing power and increasing urbanization 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. The sector currently uses about 35 percent of total cropland and about 20 percent of green water for feed production (Opio *et al.,* 2013). Globally, feed-related emissions, including those associated with land-use change, from the livestock sector account for about 3.3 gigatonnes of carbon dioxide equivalent (CO_2e). This represents about half of total emissions from livestock supply chains (Gerber *et al.*, 2013). The feed sector is aware of this, and there is a growing interest in measuring and improving the environmental performance of the feed-to-food supply chains.

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

- to develop a harmonized, science-based approach founded on a consensus among the sector's stakeholders (e.g. farmers, processors of foods and beverage products, feed millers, or compound feed producers, feed integrator producers, traders, transporters and other intermediate agents) ;
- 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.

These guidelines underwent a public review. The purpose of the review was to strengthen the advice provided and ensure it meets the needs of those seeking to improve performance through sound assessment practice. The present document is not 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 viewed as a critical next step.

The strength of the guidelines developed within the LEAP Partnership for the various livestock subsectors stems from the fact that they represent a coordinated cross-sectoral and international effort to harmonize measurement approaches. Ideally, harmonization will lead to greater understanding, transparent application and communication of metrics, and, importantly for the sector, real and measurable improvement in performance.

Rogier Schulte, Teagasc - The Agriculture and Food Development Authority, Government of Ireland (2015 LEAP chair)

Lalji Desai, World Alliance of Mobile Indigenous People (2014 LEAP chair)

Frank Mitloehner, University of California, Davis (2013 LEAP chair)

Henning Steinfeld, Food and Agriculture Organization of the United Nations, (LEAP co-chair)

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AUTHORSHIP AND DEVELOPMENT PROCESS

These guidelines are a product of the Livestock Environmental Assessment and Performance (LEAP) Partnership. Three groups contributed to their development: an *ad hoc* Technical Advisory Group (TAG), the LEAP Secretariat and the LEAP Steering Committee.

The 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, Wageningen University, Netherlands), Sophie Bertrand (Centre National Interprofessionnel de l'Economie Laitière, the International Dairy Federation), Nicolas Martin (European Feed Manufacturers' Federation,), Hans Luttikholt (United States National Oilseed Processers Association, and FEDIOL), Bruno Caputi (Sindicato Nacional da Indústria de Alimentação Animal, 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, India), Salil Arora (American Feed Industry Association), Bernard A. Lukuyu (International Livestock Research Institute, Kenya), Thumrongsakd Phonbumrung (Department of Livestock Development, Thailand), Paul Crosson (Teagasc - The Agriculture and Food Development Authority, Government of Ireland), Heinz Meissner (Agricultural Research Council, 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 ensured coherence among the various guidelines. The LEAP secretariat, hosted at the Food and Agriculture Organization (FAO) of the United Nations, was composed of: Pierre Gerber (Coordinator), Alison Watson (LEAP Manager until Dec 2013), Camillo De Camillis (LEAP manager since Feb 2014), Carolyn Opio (Technical officer), Félix Teillard (Technical officer) and Aimable Uwizeye (Technical officer).

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

Monikka Agarwal (World Alliance of Mobile Indigenous People, in LEAP since Oct 2014), Douglas Brown (World Vision), Giuseppe Luca Capodieci (The European Livestock And Meat Trading Union, International Meat Secretariat), Camillo De Camillis (FAO, LEAP manager since Feb 2014), Richard de Mooij (The European Livestock And Meat Trading Union, International Meat Secretariat), Elsa Delcombel (Government of France), Lalji Desai (World Alliance of Mobile Indigenous People, 2014 LEAP Chair), Pierre Gerber (FAO, LEAP secretariat coordinator until Jan 2015), Mathias Ginet (Government of France, in LEAP since Oct 2014), Jan Grenz (Bern University of Applied Sciences, Government of Switzerland, in LEAP

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Although not directly responsible for the preparation of these guidelines, the LEAP TAGs on poultry and small ruminants indirectly contributed to this technical document.

MULTI-STEP REVIEW PROCESS

The initial draft guidelines developed by the TAG over 2013 went through an external peer review before being revised and submitted for public review.

Laura Drauker (World Resource Institute), Christel Cederberg (Swedish Institute for Food and Biotechnology and Chalmers University of Technology, Gothenburg) John Kazer (Carbon Trust, London) peer reviewed these guidelines in late 2013. Harinder Makkar (FAO, Animal Production Officer) assisted the Secretariat in reviewing this technical document.

The LEAP Secretariat reviewed this technical guidance before its submission for both external peer review and public review. Harinder Makkar (FAO, Animal Production Officer) assisted the Secretariat in this task. The LEAP Steering Committee also reviewed the guidelines at various stages of their development and provided additional feedback before clearing their release for public review.

The public review was announced at the 1st Annual Meeting of the LEAP Partnership on 6 March 2014 and lasted until 31 July 2014. The review period was also announced to the public through an article published on the FAO website. The scientific community working on the accounting of GHG emissions from livestock was alerted through the Livestock and Climate Change Mitigation in Agriculture Discussion group on the forum of the Mitigation of Climate Change in Agriculture (MICCA) Programme,. Experts in LCA were informed through an issue of the United Nations Environment Programme (UNEP)/Society for Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative newsletter and through announcements and reminders circulated via the mailing list on LCA held by PRé Consultants. The LEAP Secretariat also publicized the 2014 LEAP public review through oral speeches in the Product Environmental Footprint (PEF) World Forum and other regional conferences. The following have participated in the public review and hence contributed to improving the quality of this technical document: Donal O'Brien and Laurence Shalloo (Teagasc - The Agriculture and Food Development Authority, Government of Ireland), Don O'Connor ((S&T)2 Consultants Inc., Canada), Tim McAllister and Sarah Meale (Agriculture and Agri-Food Canada), Michael Binder and Philippe Becquet (International Feed Industry Federation, European Union Association of Specialty Feed Ingredients and their Mixtures), Georg Schöner (BASF), Bo Weidema (2.-0 LCA consultants, Denmark), Ali Daneshi (Modares University, Iran), Anna Papagrigoraki (on behalf of the Comité Européen des Fabricants de Sucre), Armelle Gac (Institut de l'Elevage, France), Sandrine Espagnol (The French Pork and Pig Institute, France), Aurélie Wilfart and Morgane Magnin (Institut national de la recherche agronomique, France), Sylvie Dauguet (Centre Technique Interprofessionnel des Oléagineux Métropolitains, France), Aurélie Tailleur and Sarah Willmann (ARVALIS, France), Loïc Gruson (on behalf of the European Starch Industry Association), Florence Scarsi (on behalf of the French Ministry of Ecology, Sustainable Development and Energy), Alexandre Berndt (Embrapa, Brazil), Richard Sellers (on behalf of the American Feed Industry Association), and Adrian Leip, Hanna Tuomisto, Luca Zampori, Erwin Schau, Erwan Saouter and David Pennington (European Commission, Joint Research Centre).

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via funding and/or in-kind contributions: the International Dairy Federation, the International Egg Commission, the International Feed Industry Federation, the International Meat Secretariat, the International Poultry Council, the International Council of Tanners, the International Wool and Textile Organization, FEDIOL, the International Federation for Animal Health, DSM Nutritional Products AG and Novus International.

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Last but not least, the LEAP Partnership is also grateful for the advisory provided by the International Organization for Standardization (ISO), UNEP, and the European Commission, and is glad to network with the World Organisation for Animal Health and the Global Agenda for Sustainable Livestock.

Abbreviations and acronyms

CFP	Carbon footprint of a product
CHP	Combined heat and power
CO_2e	Carbon dioxide equivalent
dLUC	direct Land-Use Change
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouse Gas
GWP	Global Warming Potential
IDF	International Dairy Federation
ILCD	International Reference Life Cycle Data System
iLUC	Indirect Land-Use Change
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LEAP	Livestock Environmental Assessment and Performance Partnership
LUC	Land-Use Change
ME	Metabolizable Energy
NGO	Non-Governmental Organization
OECD	Organization for Economic Cooperation and Development
PAS	Publicly Available Specification
PCR	Product Category Rules
PEF	Product Environmental Footprint
PDF	Probability Density Functions
SETAC	Society for Environmental Toxicology and Chemistry
TAG	Technical Advisory Group
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WRI	World Resource Institute
VS	Volatile solids

Glossary

Terms relating to feed and food supply chains

Annual forage	Forage established annually, usually with annual plants, and generally involves soil disturbance, removal of existing vegetation, and other cultivation practices.
Animal by-product	Livestock production output classified in the European Union in three categories mostly due to the risk associated to the bovine spongiform encephalopathy.
Cold chain	Refers to a system for distributing products in which the goods are constantly maintained at low temperatures (e.g. cold or frozen storage and transport), as they move from producer to consumer.
Combined heat and power (CHP)	Simultaneous generation in one process of useable thermal energy together with electrical and/or mechanical energy.
Compound feed/ concentrate	Mixtures of feed materials that may contain additives for use as animal feed in the form of complete or complementary feedstuffs.
Conserved forage	Conserved forage saved for future use. Forage can be conserved in situ (e.g. stockpiling) or harvested, preserved and stored (e.g. hay, silage or haylage).
Cropping	Land on which the vegetation is dominated by large-scale production of crops for sale (e.g. maize, wheat, and soybean production).
Crop product	Product from a plant, fungus or algae cultivation system that can either be used directly as feed or as raw material in food or feed processing.
Crop residues	Materials left in an agricultural field after the crop has been harvested.
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.
Feed (feeding stuff)	Any single or multiple materials, whether processed, semi-processed or raw, which is intended to be fed directly to food producing animals. - Codex Alimentarius Code of Practice on Good Animal Feeding CAC/RCP 54 (FAO/WHO Codex Alimentarius Commission, 2008).
Feed additive	Any intentionally added ingredient not normally consumed as feed by itself, whether or not it has nutritional value, which affects the characteristics of feed or animal products. Note: Micro-organisms, enzymes, acidity regulators, trace elements, vitamins and other products fall within the scope of this definition depending on the purpose of use and method of administration. - Codex Alimentarius Code of Practice on Good Animal Feeding CAC/RCP 54 (FAO/WHO Codex Alimentarius Commission, 2008).
Feed conversion ratio	Measure of the efficiency with which an animal converts feed into tissue, usually expressed in terms of kg of feed per kg of output (e.g. live weight or protein).
Feed digestibility	Determines the relative amount of ingested feed that is actually absorbed by an animal and therefore the availability of feed energy or nutrients for growth, reproduction, etc.
Feed ingredient	A component part or constituent of any combination or mixture making up a feed, whether or not it has a nutritional value in the animal's diet, including feed additives. Ingredients are of plant, animal or aquatic origin, or other organic or inorganic substances. - Codex Alimentarius Code of Practice on Good Animal Feeding CAC/RCP 54 (FAO/WHO Codex Alimentarius Commission, 2008).
Fodder	Harvested forage fed intact to livestock, which can include fresh and dried forage.
Forage crop	Crops, annual or biennial, grown to be used for grazing or harvested as a whole crop for feed.

Medicated feed	Any feed that contains veterinary drugs as defined in the Codex Alimentarius Commission Procedural Manual. - Codex Alimentarius Code of Practice on Good Animal Feeding CAC/RCP 54 (FAO/WHO Codex Alimentarius Commission, 2008).
Natural or cross ventilation	Limited use of fans for cooling; frequently a building's sides can be opened to allow air circulation.
Natural pasture	Natural ecosystem dominated by indigenous or naturally occurring grasses and other herbaceous species used mainly for grazing by livestock and wildlife.
Packing	Process of packing products in the production or distribution stages.
Primary packaging materials	Packaging in direct contact with the product. See also: Retail packaging
Production unit	A group of activities (and the necessary inputs, machinery and equipment) in a processing facility or a farm that are needed to produce one or more co-products. Examples are the crop fields in an arable farm, the potential multiple animal herds that are common in smallholder operations (sheep, goats deer, dairy cattle, suckling cattle or even rearing of heifers, production of milk, etc.), or the individual processing lines in a manufacturing facility.
Retail packaging	Containers and packaging that reach consumers.
Secondary packaging materials	Additional packaging, not contacting the product, which may be used to contain relatively large volumes of primary packaged products or transport the product safely to its retail or consumer destination.
Silage	Forage harvested and preserved (at high moisture contents generally greater than 500 g per kg) by organic acids produced during partial anaerobic fermentation.
Volatile solids	Volatile solids (VS) are the organic material in livestock manure and consist of both biodegradable and non-biodegradable fractions. VS are measured as the fraction of sludge combusted at 550 degrees Celsius after 2 hours.

Terms relating to environmental accounting and environmental assessment

Acidification

Impact category that addresses impacts due to acidifying substances in the environment. Emissions of nitrogen oxides (NO_x), ammonia (NH_3) and sulphur oxides (SO_x) lead to releases of hydrogen ions (H+) when the gases are mineralised. The protons contribute to the acidification of soils and water when they are released in areas where the buffering capacity is low. Acidification may result to forest decline and lake acidification
- Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

Activity data

Data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time (UNFCCC, n.d.).

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.
- ISO 14044:2006, 3.17 (ISO, 2006c)

Anthropogenic

Relating to, or resulting from the influence of human beings on nature

Attributional modelling approach

System modelling approach in which inputs and outputs are attributed to the functional unit of a product system by linking and/or partitioning the unit processes of the system according to a normative rule.
- *Global Guidance Principles for Life Cycle Assessment Databases* (UNEP/SETAC Life Cycle Initiative, 2011)

Background system

The background system consists of processes on which no or, at best, indirect influence may be exercised by the decision-maker for which an LCA is carried out. Such processes are called "background processes."
- *Global Guidance Principles for Life Cycle Assessment Databases* (UNEP/SETAC Life Cycle Initiative, 2011)

Biogenic carbon

Carbon derived from biomass.
- ISO/TS 14067:2013, 3.1.8.2 (ISO, 2013a)

Biomass

Material of biological origin excluding material embedded in geological formations and material transformed to fossilized material, and excluding peat.
- ISO/TS 14067:2013, 3.1.8.1 (ISO, 2013a)

Capital goods Capital goods are final products that have an extended life and are used by the company to manufacture a product; provide a service; or sell, store, and deliver merchandise. In financial accounting, capital goods are treated as fixed assets or as plant, property and equipment. Examples of capital goods include equipment, machinery, buildings,facilities, and vehicles
- *Technical Guidance for Calculating Scope 3 Emissions*, Chapter 2 (WRI and WBCSD, 2011b)

Carbon dioxide equivalent (CO_2 e) Unit for comparing the radiative forcing of a greenhouse gas (GHG) to that of carbon dioxide.
- ISO/TS 14067:2013, 3.1.3.2 (ISO, 2013a)

Carbon footprint of a product (CFP) Sum of greenhouse gas emissions and removals in a product system, expressed as CO_2equivalents and based on a life cycle assessment using the single impact category of climate change.
- ISO/TS 14067:2013, 3.1.1.1 (ISO, 2013a)

Carbon storage Carbon removed from the atmosphere and stored as carbon.
- ISO 16759:2013, 3.1.4 (ISO, 2013b)

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 impact category "climate change", CO_2 is chosen as the reference substance and kg CO_2-equivalents as the reference unit.
- Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

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.
- ISO 14044:2006, 3.37 (ISO, 2006c)

Classification Assigning the material/energy inputs and outputs tabulated in the Life Cycle Inventory to impact categories according to each substance's potential to contribute to each of the impact categories considered.
- Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

Combined production A multifunctional process in which production of the various outputs can be independently varied. For example in a backyard system the number of poultry and swine can be set independently.

Comparative assertion
Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function.
- ISO 14044:2006, 3.6 (ISO, 2006c)

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 data modelling
System modelling approach in which activities in a product system are linked so that activities are included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit.
- *Global Guidance Principles for Life Cycle Assessment Databases* (UNEP/SETAC Life Cycle Initiative, 2011)

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
Note 1: Consumables differ from capital goods in that they have an expected life of one year or less, or a need to replenish on a one year or less basis (e.g. lubricating oil, tools and other rapidly wearing inputs to a process).
Note 2: Fuel and energy inputs to the life cycle of a product are not considered to be consumables.
- PAS 2050:2011, 3.10 (BSI, 2011)

Co-production
A generic term for multifunctional processes; either combined- or joint-production.

Co-products
Any of two or more products coming from the same unit process or product system.
- ISO 14044:2006, 3.10 (ISO, 2006c)

Cradle-to-gate
Life-cycle stages from the extraction or acquisition of raw materials to the point at which the product leaves the organization undertaking the assessment. - PAS 2050:2011, 3.13 (BSI, 2011)

Critical review
Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment.
- ISO 14044:2006, 3.45 (ISO, 2006c)

Critical review report	Documentation of the critical review process and findings, including detailed comments from the reviewer(s) or the critical review panel, as well as corresponding responses from the practitioner of the LCA study. - ISO 14044:2006, 3.7 (ISO, 2006c)
Cut-off criteria	Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study. - ISO 14044:2006, 3.18 (ISO, 2006c)
Data quality	Characteristics of data that relate to their ability to satisfy stated requirements. - ISO 14044:2006, 3.19 (ISO, 2006c)
Dataset (both LCI dataset and LCIA dataset)	A document or file with life cycle information of a specified product or other reference (e.g. site, process), covering descriptive metadata and quantitative life cycle inventory and/or life cycle impact assessment data, respectively. - *International Reference Life Cycle Data System (ILCD) Handbook: General guide for Life Cycle Assessment - Detailed guidance* (European Commission, 2010b)
Delayed emissions	Emissions that are released over time, e.g. through prolonged use or final disposal stages, versus a single, one-time emission. - Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Direct Land-Use Change (dLUC)	Change in human use or management of land within the product system being assessed. - ISO/TS 14067:2013, 3.1.8.4 (ISO, 2013a)
Direct energy	Energy used on farms for livestock production activities (e.g. lighting, heating).
Downstream	Occurring along a product supply chain after the point of referral. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

Drainage basin	Area from which direct surface runoff from precipitation drains by gravity into a stream or other water body. Note 1: The terms 'watershed', 'drainage area', 'catchment', 'catchment area' or 'river basin' are sometimes used for the concept of 'drainage basin'. Note 2: Groundwater drainage basin does not necessarily correspond in area to surface drainage basin. Note 3: The geographical resolution of a drainage basin should be determined at the goal and scope stage: it may regroup different sub drainage basins. - ISO 14046:2014, 3.1.8 (ISO, 2014)
Economic value	Average market value of a product at the point of production possibly over a 5-year time frame. - Adapted from: PAS 2050:2011, 3.17 (BSI, 2011) Note 1: Where barter is in place, the economic value of the commodity traded can be calculated on the basis of the market value and amount of the commodity exchanged.
Eco-toxicity	Environmental impact category that addresses the toxic impacts on an ecosystem, which damage individual species and change the structure and function of the ecosystem. Eco-toxicity is a result of a variety of different toxicological mechanisms caused by the release of substances with a direct effect on the health of the ecosystem. - Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Elementary flow	Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation. - ISO 14044:2006, 3.12 (ISO, 2006c)
Emission factor	Amount of greenhouse gases emitted, expressed as carbon dioxide equivalent and relative to a unit of activity (e.g. kg CO_2e per unit input). - Adapted from UNFCCC (n.d.) Note: Emission factor data is obtained from secondary data sources.
Emissions	Release of substance to air and discharges to water and land.

Environmental impact	Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services. - ISO/TR 14062:2002, 3.6 (ISO, 2002)
Eutrophication	Excess of nutrients (mainly nitrogen and phosphorus) in water or soil, from sewage outfalls and fertilized farmland. In water, eutrophication 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. In soil, eutrophication favours nitrophilous plant species and modifies the composition of the plant communities. - Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
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. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Final product	Goods and services that are ultimately consumed by the end user rather than used in the production of another good or service. - *Product Life Cycle Accounting and Reporting Standard* (WRI and WBCSD, 2011a)
Foreground system	The foreground system consists of processes which are under the control of the decision-maker for which an LCA is carried out. They are called "foreground processes". - *Global Guidance Principles for Life Cycle Assessment Databases* (UNEP/SETAC Life Cycle Initiative, 2011)
Functional unit	Quantified performance of a product system for use as a reference unit. - ISO 14044:2006, 3.20 (ISO, 2006c) It is essential that the functional unit allows comparisons that are valid where the compared objects (or time series data on the same object, for benchmarking) are comparable.
GHG removal	Mass of a GHG removed from the atmosphere. - ISO/TS 14067:2013, 3.1.3.6 (ISO, 2013a)

Global Warming Potential (GWP)	Characterization factor describing the radiative forcing impact of one mass-based unit of a given GHG relative to that of carbon dioxide over a given period of time. - ISO/TS 14067:2013, 3.1.3.4 (ISO, 2013a).
Greenhouse gases (GHGs)	Gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. - ISO 14064-1:2006, 2.1 (ISO, 2006d)
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. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
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, penetration through the skin insofar as they are related to non-cancer effects that are not caused by particulate matter/respiratory inorganics or ionising radiation. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Indirect Land-Use Change (iLUC)	Change in the use or management of land which is a consequence of direct land-use change, but which occurs outside the product system being assessed. - ISO/TS 14067:2013, 3.1.8.5 (ISO, 2013a)
Impact category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned. - ISO 14044:2006, 3.39 (ISO, 2006c)
Impact category indicator	Quantifiable representation of an impact category. - ISO 14044:2006, 3.40 (ISO, 2006c)
Infrastructure	Synonym for capital good.
Input	Product, material or energy flow that enters a unit process. - ISO 14044:2006, 3.21 (ISO, 2006c)

Ionizing radiation, human health	Impact category that accounts for the adverse health effects on human health caused by radioactive releases. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Intermediate product	Output from a unit process that is input to other unit processes that require further transformation within the system. - ISO 14044:2006, 3.23 (ISO, 2006c)
Joint production	A multi-functional process that produces various outputs, such as meat and eggs in backyard systems. Production of the different goods cannot be independently varied, or only varied within a very narrow range.
Land occupation	Impact category related to use (occupation) of land area by activities, such as agriculture, roads, housing and mining. - Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Land-use change	Change in the purpose for which land is used by humans (e.g. between crop land, grass land, forestland, wetland, industrial land). - PAS 2050:2011, 3.27 (BSI, 2011)
Life cycle	Consecutive and interlinked stages of a product system, from raw materialacquisition or generation from natural resources to final disposal. - ISO 14044:2006, 3.1 (ISO, 2006c)
Life Cycle Assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. - ISO 14044:2006, 3.2 (ISO, 2006c)
Life cycle GHG emissions	Sum of GHG emissions resulting from all stages of the life cycle of a product and within the specified system boundaries of the product. - PAS 2050:2011, 3.30 (BSI, 2011)
Life Cycle Impact Assessment (LCIA)	Phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential impacts for a product system throughout the life cycle of the product. - Adapted from: ISO 14044:2006, 3.4 (ISO, 2006c)

Life Cycle Inventory (LCI)	Phase of LCA involving the compilation and quantification of inputs and outputs for a product throughout its life cycle. - ISO 14046:2014, 3.3.6 (ISO, 2014)
Life Cycle Interpretation	Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations. - ISO 14044:2006, 3.5 (ISO, 2006c)
Material contribution	Contribution from any one source of GHG emissions of more than 1% of the anticipated total GHG emissions associated with the product being assessed. Note: A materiality threshold of 1 percent has been established to ensure that very minor sources of life cycle GHG emissions do not require the same treatment as more significant sources. - PAS 2050:2011, 3.31 (BSI, 2011)
Multi-functionality	If a process or facility provides more than one function, i.e. if it delivers several goods and/or services ('co-products'), it is 'multi-functional'. 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. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
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 analysed system in terms of the total contributions to each impact category per reference unit. When displaying the normalized 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 analysed system. Normalized impact assessment results reflect only the contribution of the analysed system to the total impact potential, not the severity/relevance of the respective total impact. Normalized results are dimensionless, but not additive. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

Offsetting Mechanism for compensating for all or for a part of the carbon footprint of a product through the prevention of the release of, reduction in, or removal of an amount of greenhouse gas emissions in a process outside the boundary of the product system.
- ISO/TS 14067:2013, 3.1.1.4 (ISO, 2013a)

Output Product, material or energy flow that leaves a unit process.
- ISO 14044:2006, 3.25 (ISO, 2006c)

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. chlorofluorocarbons, hydrochlorofluorocarbon, Halons)
- *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

Particulate matter Impact category that accounts for the adverse health effects on human health caused by emissions of Particulate Matter (PM) and its precursors (NOx, SOx, NH3)
- *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

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.
- *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

Primary data Quantified value of a unit process or an activity obtained from a direct measurement or a calculation based on direct measurements at its original source.
- ISO 14046:2014, 3.6.1 (ISO, 2014)

Primary activity data Quantitative measurement of activity from a product's life cycle that, when multiplied by the appropriate emission factor, determines the GHG emissions arising from a process. Examples of primary activity data include the amount of energy used, material produced, service provided or area of land affected.
- PAS 2050:2011, 3.34 (BSI, 2011)

Product(s) Any goods or service.
- ISO 14044:2006, 3.9 (ISO, 2006c)

Product category	Group of products that can fulfil equivalent functions. - ISO 14046:2014, 3.5.9 (ISO, 2014)
Product category rules (PCR)	Set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories. - ISO 14025:2006, 3.5 (ISO, 2006a)
Product system	Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product. - ISO 14044:2006, 3.28 (ISO, 2006c)
Proxy data	Data from a similar activity that is used as a stand-in for the given activity. Proxy data can be extrapolated, scaled up, or customized to represent the given activity. For example, using a Chinese unit process for electricity production in an LCA for a product produced in Viet Nam. - *Product Life Cycle Accounting and Reporting Standard* (Global Protocol, 2011a)
Raw material	Primary or secondary material that is used to produce a product. - ISO 14044:2006, 3.1.5 (ISO, 2006c)
Reference flow	Measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit. - ISO 14044:2006, 3.29 (ISO, 2006c)
Releases	Emissions to air and discharges to water and soil. - ISO 14044:2006, 3.30 (ISO, 2006c)
Reporting	Presenting data to internal management or external users such as regulators, shareholders, the general public or specific stakeholder groups. - Adapted from: *ENVIFOOD Protocol* (Food SCP RT, 2013)

Residue or Residual	Substance that is not the end product (s) that a production process directly seeks to produce. - Communication from the European Commission 2010/C 160/02 (European Commission, 2010a). More specifically, a residue is any material without economic value leaving the product system in the condition as it created in the process, but which has a subsequent use. There may be value-added steps beyond the system boundary, but these activities do not impact the product system calculations. Note 1: Materials with economic value are considered products. Note 2: Materials whose economic value is both negligible relative to the annual turnover of the organization, and is also entirely determined by the production costs necessary not to turn such materials in waste streams are to be considered as residues from an environmental accounting perspective. Note 3: Those materials whose relative economic value volatility is high in the range of positive and negative value, and whose average value is negative are residues from an environmental accounting perspective. Materials economic value volatility is possibly calculated over a 5-year time frame at the regional level.
Resource depletion	Impact category that addresses use of natural resources either renewable or non-renewable, biotic or abiotic. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Secondary data	Data obtained from sources other than a direct measurement or a calculation based on direct measurements at the original source. - ISO 14046:2014, 3.6.2 (ISO, 2014) Secondary data are used when primary data are not available or 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 outcome of a study. - ISO 14044:2006, 3.31 (ISO, 2006c)
Sink	Physical unit or process that removes a GHG from the atmosphere. - ISO 14064-1:2006, 2.3 (ISO, 2006d).

Soil Organic Matter (SOM)	The measure of the content of organic material in soil. This derives from plants and animals and comprises all of the organic matter in the soil exclusive of the matter that has not decayed. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
System boundary	Set of criteria specifying which unit processes are part of a product system. - ISO 14044:2006, 3.32 (ISO, 2006c)
System expansion	Expanding the product system to include additional functions related to co-products.
Temporary carbon storage	It happens when a product "reduces the GHGs in the atmosphere" or creates "negative emissions", by removing and storing carbon for a limited amount of time. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
Tier-1 method	Simplest method that relies on single default emission factors (e.g. kg methane per animal).
Tier-2 method	A more complex approach that uses detailed country-specific data (e.g. gross energy intake and methane conversion factors for specific livestock categories).
Tier-3 method	Method based on sophisticated mechanistic models that account for multiple factors such as diet composition, product concentration from rumen fermentation, and seasonal variation in animal and feed parameters.
Uncertainty analysis	Systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability. - ISO 14044:2006, 3.33 (ISO, 2006c)
Unit process	Smallest element considered in the life cycle inventory analysis for which input and output data are quantified. - ISO 14044:2006, 3.34 (ISO, 2006c)
Upstream	Occurring along the supply chain of purchased goods/services prior to entering the system boundary. - *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

Waste	Substances or objects which the holder intends or is required to dispose of. - ISO 14044:2006, 3.35 (ISO, 2006c) Note 1: Deposition of manure on a land where quantity and availability of soil nutrients such as nitrogen and phosphorus exceed plant nutrient requirement is considered as a waste management activity from an environmental accounting perspective. Derogation is only possible whereas evidences prove that soil is poor in terms of organic matter and there is no other way to build up organic matter. See also: Residual and Economic value.
Water body	Entity of water with definite hydrological, hydrogeomorphological, physical, chemical and biological characteristics in a given geographical area (e.g. lakes, rivers, groundwater, seas, icebergs, glaciers and reservoirs). Note 1: In case of availability, the geographical resolution of a water body should be determined at the goal and scope stage: it may regroup different small water bodies. - ISO 14046:2014, 3.1.7 (ISO, 2014)
Water use	Use of water by human activity. Note 1: Use includes, but is not limited to, any water withdrawal, water release or other human activities within the drainage basin impacting water flows and/or quality, including in-stream uses such as fishing, recreation, transportation. Note 2: The term 'water consumption' is often used to describe water removed from, but not returned to, the same drainage basin. Water consumption can be because of evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea. Change in evaporation caused by land-use change is considered water consumption (e.g. reservoir). The temporal and geographical coverage of the water footprint assessment should be defined in the goal and scope. - ISO 14046:2014, 3.2.1 (ISO, 2014)
Water withdrawal	Anthropogenic removal of water from any water body or from any drainage basin, either permanently or temporarily. - ISO 14046:2014, 3.2.2 (ISO, 2014)

Weighting

Weighting is an additional, but not mandatory, step that may support the interpretation and communication of the results of the analysis. Impact assessment results are multiplied by a set of weighting factors, which reflect the perceived relative importance of the impact categories considered. Weighted impact assessment results can be directly compared across impact categories, and also summed across impact categories to obtain a single-value overall impact indicator. Weighting requires making value judgements as to the respective importance of the impact categories considered. These judgements may be based on expert opinion, social science methods, cultural/political viewpoints, or economic considerations.
- Adapted from: *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)

Summary of Recommendations for the LEAP guidance

ENVIRONMENTAL PERFORMANCE OF LARGE RUMINANT SUPPLY CHAINS: GUIDELINES FOR QUANTIFICATION

The methodology developed in these guidelines aims to introduce a harmonised international approach to the assessment of the environmental performance of large ruminant supply chains in a manner that takes account of the specificity of the various production systems involved. It aims to increase understanding of large ruminant 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 methods, metrics and data.

The table below summarises the major recommendations of the technical advisory group for performance of lifecycle assessment to evaluate environmental performance of large ruminant supply chains. It is intended to provide a condensed overview and information on location of specific guidance within the document.

LEAP guidance uses a precise language to indicate which provisions of the guidelines are requirements, which are recommendations, and which are permissible or allowable options that intended user may choose to follow. The term “shall” is used in this guidance to indicate what is required. 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. In addition, as general rule, assessments and guidelines claiming to be aligned with the present LEAP guidelines should flag and justify with reasoning any deviations.

Topic	Summary recommendation	Section
DEFINITION OF THE PRODUCT GROUP		7
Product description	Feed is defined as material fed to animals in any form. Additives and supplements are covered by reference to secondary sources.	7.1
Life cycle stages: modularity.	The guideline support modularity to allow flexibility in modeling systems. The main stages covered include cultivation, transport, processing, compounding and on-farm storage/delivery to the animal.	7.2
GOAL AND SCOPE DEFINITION		8
Goal of the LCA study	The goal shall define: the subject, purpose, intended use and audience, limitations, whether internal or external critical review is required, and the study commissioner.	8.1
Scope of the LCA	The scope shall define: the process and functions of the system, the functional unit and system boundaries, allocation principles and impact categories.	8.2
Reference flows	Dry matter and gross energy content of each reference flow material should be specified as meta-data. For crop rotations, a full rotation should be accounted.	8.3
System boundary		8.4
General / Scoping analysis	The system boundary shall be defined following general supply chain logic including all phases from raw material extraction to the point at which the functional unit is produced. Scoping analysis may use input-output data and should cover impact categories specified by the study goal.	8.4.1
Feed production stage	Includes ingredients of both plant (cultivation of row crops, forage and pasture) and animal origin (blood or bone meal).	8.4.2
Feed processing stage	Defined by a gate-to gate boundary beginning with receipt of raw materials and ending with processed products, for example rape seed meal.	8.4.3
Compound feed production stage	Defined by a gate-to-gate boundary process to compound processed or raw feed material at a feed mill, to produce a partial or complete ration, ready for transport.	8.4.4
On-farm (animal production) stage	Accounting for of delivery of feed or ingredients to the farm and distribution to the animal for consumption is explicitly included.	8.4.5
Transport and trade	Transport, trade and the related storage are intermediate steps within the feed production stages. The upstream and downstream system boundaries depend on the respective stages.	8.4.6
Criteria for system boundary	Preparation of a system diagram documenting main transformation steps the material flows is recommended. Feed LCAs should also include all emissions associated with land use and land-use change. Emissions related to feed production shall be included regardless of specific production location.	8.4.7
Material contribution and threshold	Flows contributing less than 1% to impacts may be cut off, provided that 95% of each impact category is accounted, based on a scoping analysis.	8.4.8
Time boundary for data	Shall include: full crop rotation cycle; feed characteristics (grasses with seasonal variation); establishment, juvenile growth, and adult stage for perennial crops. In case of significant inter-annual variability, the one-year time boundary should be determined using multiple-year average data to meet representativeness criteria.	8.4.9 10.4.1
Capital goods	May be excluded if the lifetime is greater than one year.	8.4.10
Ancillary activities	Should be included if relevant, as determined by scoping analysis.	8.4.11
Delayed emissions	Adoption of PAS 2050 – 2011, except for land use and land-use change and lime and urea application., for which specific guidelines are provided.	8.4.12
Carbon offsets	Shall not be included in the impact characterization, but may be reported separately.	8.4.13
Impact categories and characterisation methods	Climate change (IPCC, GWP100)-including land use change contribution to climate change (PAS 2050); fossil energy demand (ReCiPe); land occupation (as inventory data); acidification and eutrophication (ReCiPe).	8.5

(Cont.)

Topic	Summary recommendation	Section
MULTI-FUNCTIONAL PROCESSES AND ALLOCATION		9
General principles	Follow ISO 14044 standard (section 4.3.4) – with restrictions on application of system expansion. The application of consequential modeling is not supported by these guidelines. System expansion may be used in the context of including expanded functionality. For example, calculating whole facility impacts of soybean processing without separately assigning impacts to oil and meal as co-products.	9.1
Methodological choices	Guidance for separation of complicated multifunctional systems and application of bio-physical, economic, or physical (least preferred) allocation when process separation is not feasible. A decision tree is presented to facilitate division of complicated processes into separate production units, and subsequently into individual products.	9.2
Allocation of transport	The load factor shall account for empty transport distance, maximum load (mass for volume limited), and use physical causality (mass or volume share) for simultaneous transport of multiple products.	9.2.1
Allocation of manure (used as a fertiliser)	Refer to LEAP guidelines for animal production. These guidelines only cover application and decomposition of manure applied as fertiliser; if situations where manure is a co-product of the livestock system (as opposed to being a residual), close coordination with the livestock system is required to estimate the incoming burden of the manure to the crop system.	9.2.2
COMPILING AND RECORDING INVENTORY DATA		10
General principles	Inventory should be aligned with the goal and scope, shall include all resource use and emissions within the defined system boundaries that are relevant to the chosen impact categories. Primary data are preferred, where possible. Data sources and quality shall be documented.	10.1
Collection of data	Primary and secondary data are described. A data management plan is recommended which should address: data collection procedures; data sources; calculation methodologies; data storage procedures; and quality control and review procedures	10.2
Primary activity data	To the full extent possible, primary data are recommended for all foreground processes, those under control of the study commissioner.	10.2.1
Secondary and default data	Data from existing databases, peer-reviewed literature, may be used for background processes, or some foreground processes that are minor contributors to total emissions. Secondary data is also subject to data quality requirements.	10.2.2
Data for feed additives	Secondary data should be used.	10.2.3
Addressing LCI data gaps	Proxy data may be used, with assessment of the uncertainty. Environmentally extended input-output tables may also be used where available.	10.2.4
Data quality assessment	LCI data quality assessment shall address representativeness, completeness, consistency, precision/uncertainty, and methodological appropriateness.	10.3
Uncertainty analysis	Uncertainty information should be collected along with a primary data. If possible, the standard deviation should be estimated, if not a reasonable range should be estimated.	10.4
LIFE CYCLE INVENTORY		11
Overview	Inventory should be aligned with the goal and scope, and shall include all resources use and emissions within the defined system boundaries that are relevant to the chosen impact categories and shall support the attribution of emissions and resources use to single production units and co-products. Primary data are preferred, where possible. Data sources and quality shall be documented.	11.1

(Cont.)

Topic	Summary recommendation	Section
Cultivation		11.2
Description of the cultivation system	Complex cultivation systems must be carefully defined: annual versus perennial; multi-season or multi-year crop rotations; multiple harvests or crops from a single field in a given year. The time boundary for data collection should be appropriate to account for these as well as seasonal and inter-annual effects.	11.2.1
Relevant inputs, resource use and emissions during cultivation	Data should be collected covering all relevant activities for crop production: fertilizer manufacturing and application rates, manure and crop protection chemical application, fuel and other inputs as well as associated emissions. In addition, land use change related to the product system, and its effect on climate change shall be recorded and separately reported.	11.2.2
Processing of feed materials		11.3
Feed processing system	Multiple steps resulting in multiple co-products may occur. Purification and concentration as well as processing to increase digestibility may be included.	11.3.1
Relevant inputs, resource use and emissions	Inputs include raw feed materials as well as other ingredients and energy for processing. Emissions data to support the suite of impact categories defined in the goal and scope shall be collected.	11.3.2
Constructing process inventory tables from aggregated or partial data	If only aggregated data for facility are available, an input-output analysis may be used. Upstream burdens (cultivation) for crop residues (beat or citrus pulp, spent grain, etc.) shall not be accounted; only the processing energy at the facility is included for these materials. Default allocation values are provided for a number of common processing (milling) technologies.	11.3.3
Compound feed production		11.4
Compound feed production system	Combining multiple ingredients on the basis of their nutrient profiles to meet specific animal needs, based on species and production phase.	11.4.1
Relevant inputs, resource use and emissions	A balance to account for all input ingredients, regardless of origin (grains, processed feeds, or animal products), including storage loss, and fossil and other energy consumption shall be used.	11.4.2
On-farm ration management		11.5
Feed processing at the livestock farm	All processes occurring on the livestock farm related to management of and delivery to produced or purchased feed to the animal shall be included in the inventory.	11.5.1
Relevant emissions and resource use	Data may be required from several stages: reception in storage; removal from storage; treatment; mixing; and feeding. For mechanised systems, energy requirements must be accounted. Further, in many systems some feed is lost or wasted and this shall be fully accounted.	11.5.2
Intermediate transport and trade		11.6
Transport and trade	All activities for which transport is required, for both inputs and outputs at each stage in the lifecycle of the feed product shall be accounted.	11.6.1
Relevant inputs, resource use and emissions	The type of product, transport distance and mode, storage loss, and ancillary energy requirements for storage (e. g., refrigeration or ventilation) shall be included in the inventory.	11.6.2
INTERPRETATION OF LCA RESULTS		12
Identification of key issues	The practitioner shall evaluate the completeness (with respect to the goal and scope); shall perform sensitivity checks (methodological choices); and consistency checks (methodological choices, data quality assessment and impact assessment steps)	12.1
Characterising uncertainty	Data uncertainty should be reported through formal quantitative analysis or by qualitative discussion, depending upon the goal and scope.	12.2

(Cont.)

Topic	Summary recommendation	Section
Conclusions, Recommendations and Limitations	Within the context of the goal and scope, the main results and recommendations should be presented and limitations which may impact robustness of results clearly articulated.	12.3
Use and comparability of results	These guidelines support cradle-to-animal LCA and do not include guidance for post-processing, distribution, consumption or end of life activities.	12.4
Report elements and structure	The following elements should be included: Executive summary summarising the main results and limitations; identification of the practitioners and sponsor; goal and scope definition (boundaries, functional unit, materiality and allocation); lifecycle inventory modeling and life cycle impact assessment; results and interpretation, including limitations and trade-offs. A statement indicating third-party verification for reports to be released to the public.	12.6

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 LCA. The main purpose of the guidelines is to provide a sufficient definition of the calculation methods and data requirements needed to enable a consistent application of LCA across the diverse spectrum of feed supply chains.

This guidance is relevant to a wide range 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; and
- policy makers interested in developing accounting and reporting specifications for livestock supply chains.

The benefits of this approach include:

- the use of recognized, robust and transparent methodology developed to take account of the nature of feed supply chains;
- the identification of supply chain hotspots and opportunities to improve and reduce environmental impact;
- the identification of opportunities to increase efficiency and productivity;
- the ability to benchmark performance internally or against industry standards;
- the provision of support for reporting and communication requirements; and
- awareness raising 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: climate change, fossil energy use, acidification, eutrophication and land use. This document does not provide support for the assessment of comprehensive environmental performance nor the social or economic aspects of feed supply chains.

It is intended that in future these guidelines will be updated to include multiple categories, if enough reliable data become available to justify the changes.

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 relates to the time frame, as 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, and water depletion. 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 strives for a pragmatic balance between flexibility and rigorous consistency across the scales, geographic locations 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 LEAP guidelines are 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 ona full LCA. 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 World Trade Organization requirements.

3. Structure and conventions

3.1 STRUCTURE

This document adopts the main structure of ISO 14040:2006 and the four main phases of LCAs; goal and scope definition, inventory analysis, impact assessment, and interpretation. Figure 1 presents 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 practices in reporting.

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

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 and published 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 to facilitate measurement of the GHG emissions from the animal sectors.

3.2 PRESENTATIONAL CONVENTIONS

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

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

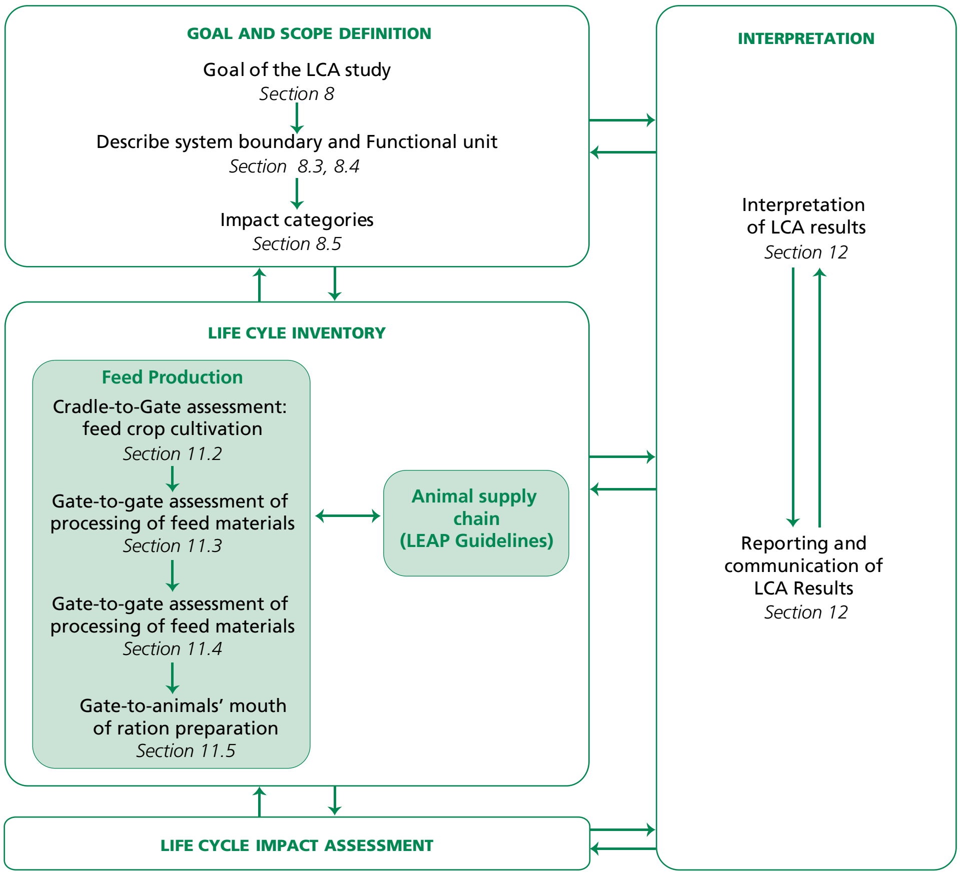
The term "should" is used to indicate a recommendation, but not a requirement.

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.

Figure 1
Main life cycle steps in the animal feed supply chain



4. Essential background information and principles

4.1 A BRIEF INTRODUCTION TO LCA

LCA is recognized as one of the most complete and widely used methodological frameworks for assessing 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 reducing environmental impacts. According to ISO14040:2006, LCAs consist of four phases:

- goal and scope definition, including appropriate metrics (e.g. GHG emissions, water consumption, hazardous materials generated and/or quantity of waste);
- life cycle inventories (LCIs), i.e. the collection of data that identify the system inputs and outputs and discharges to the environment;
- performance of impact assessment, i.e. the application of characterization factors to the LCI emissions that normalizes groups of emissions to a common metric, such as global warming potential reported in carbon dioxide equivalents (CO_2 e); and
- analysis and interpretation of results.

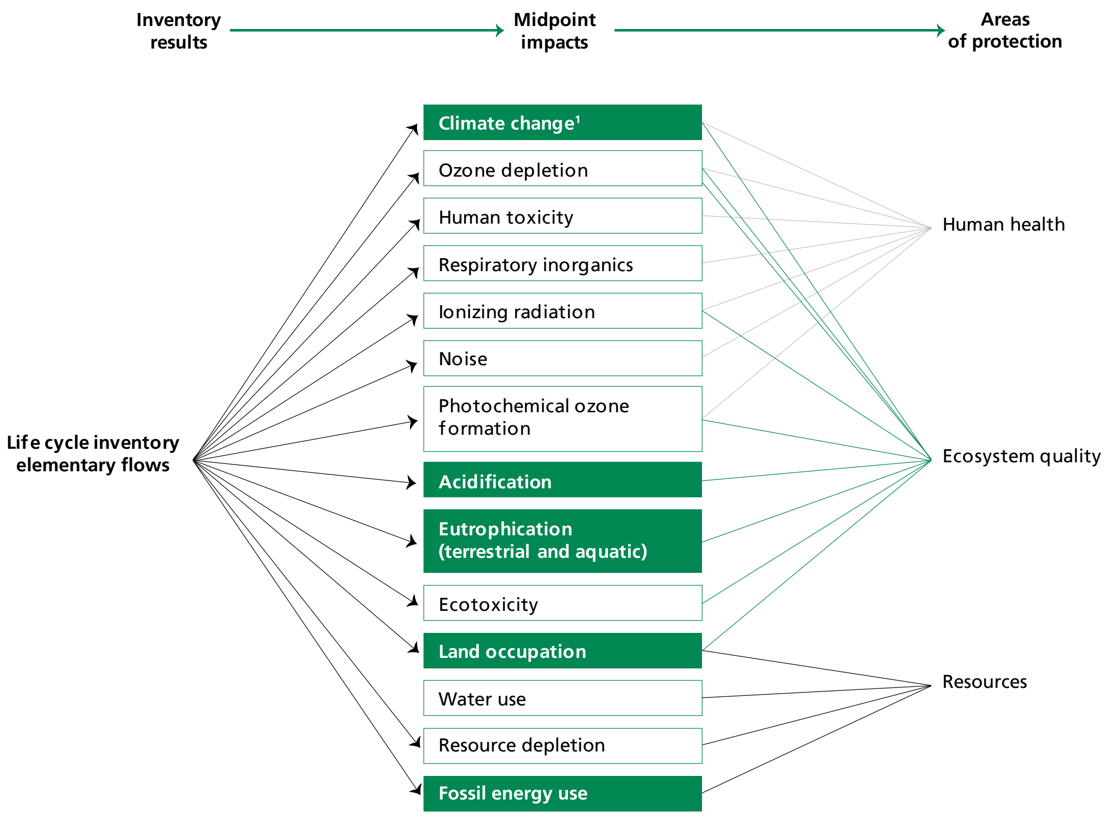
4.2 ENVIRONMENTAL IMPACT CATEGORIES

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 LCI to midpoint and endpoint impact categories (Figure 2).

A distinction must be made between midpoint impacts, which characterize impacts 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 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 LCI are the amounts of GHG emissions per functional unit. Based on a radiative forcing model, characterization factors, known as global warming potentials, specific to each GHG, can be used to aggregate all of the emissions to the same midpoint impact category indicator, i.e. kilograms of CO_2e per functional unit.

Figure 2
Environmental cause-effect chain and categories of impact



Midpoint impact category covered in these guidelines

Source: dapted from the International Reference Life Cycle Data System (ILCD) Handbook (European Commission 2010b, 2011).

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* (ISO, 2006b)
  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 defines the generic steps that 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, 2006c)
  ISO 14044:2006 specifies requirements and provides guidelines for LCA including: definition of the goal and scope of the LCA, the LCI, the LCIA, the life cycle interpretation, 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.

4.4 NON-NORMATIVE REFERENCES

- ISO 14025:2006 *Environmental labels and declarations – Type III environmental declarations – Principles and procedures* (ISO, 2006a)
  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, 2013a)
  ISO/TS 14067:2013 specifies the principles, requirements and guidelines for the quantification and communication of the carbon footprint of a product. It is based on ISO 14040:2006 and ISO 14044:2006 for quantification, and ISO 14020:2000 (ISO, 2000), ISO 14024:1999 (ISO, 1999) and ISO 14025:2006, which deal with environmental labels and declarations, for communication.
- *Product Life Cycle Accounting and Reporting Standard* (WRI and WBCSD, 2011a)
  This standard from the World Resources Institute (WRI) and the World Business Council for Sustainable Development (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 puts more emphasis on analysis, tracking changes over time, reduction options and reporting. Like PAS2050:2011 (see below), this standard excludes impacts from the production of infrastructure, but whereas PAS2050:2011 includes 'operation of premises', such as retail lighting or office heating, the *Product Life Cycle Accounting and Reporting Standard* does not.
- *ENVIFOOD Protocol, Environmental Assessment of Food and Drink Protocol* (Food SCP RT, 2013)
  The Protocol was developed by the European Food Sustainable Consumption Round Table to support a number of environmental instruments for use in communication and the identification of environmental improvement options. The Protocol might be the baseline for developing communication methods, product category rules (PCRs), criteria, tools, datasets and assessments.
- *International Reference Life Cycle Data System (ILCD), 2010a., ILCD Handbook: - General guide for Life Cycle Assessment - Detailed guidance* (European Commission, 2010b)

The ILCD Handbook was published in 2010 by the European Commission Joint Research Centre and provides detailed guidance for LCA based on ISO 14040 and 14044. It consists of a set of documents, including a general guide for LCA, as well as specific guides for LCI and LCIA.

- *Product Environmental Footprint (PEF) Guide* (European Commission, 2013)
  This Guide is a general method to measure and communicate the potential life cycle environmental impact of a product developed by the European Commission primarily to highlight the discrepancies in environmental performance information.
- *BPX-30-323-0 General principles for an environmental communication on mass market products - Part 0: General principles and methodological framework* (AFNOR, 2011)
  This is a general method developed by the ADEME-AFNOR stakeholder platform to measure and communicate the potential life cycle environmental impact of a product. It was developed under request of the French Government, again with the purpose of highlighting the discrepancies in environmental performance information. Food production specific guidelines are also available, along with a large set of product specific rules on livestock products.
- *PAS 2050:2011 Specification for the assessment of life cycle greenhouse gas emissions of goods and services* (BSI, 2011)
  PAS 2050:2011 is a Publicly Available Specification (PAS), i.e. a not standard specification. An initiative of the United Kingdom sponsored by the Carbon Trust and the Department for Environment, Food and Rural Affairs, PAS 2050:2011 was published through the British Standards Institution (BSI) and uses BSI methods for agreeing on a PAS. It is designed for applying LCA over a wide range of products in a consistent manner for industry users, focusing solely on the carbon footprint indicator. PAS 2050:2011 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).

4.5 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 ISO 14040:2006, the *Product Environmental Footprint (PEF) Guide*, the *Product Life Cycle Accounting and Reporting Standard*, PAS 2050:2011, the *ILCD Handbook* and ISO/TS 14067:2013, and are intended to guide the accounting and reporting of GHG emissions and fossil energy use.

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

Life cycle perspective

"LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal. Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided" (ISO 14040:2006, 4.1.2).

Relative approach and functional unit

LCA is a relative approach, which is structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit (ISO 14040:2006, 4.1.4).

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

Quantification of the product environmental performance shall include all environmentally relevant material/energy flows and other environmental interventions as required for adherence to the defined system boundaries, the data requirements, and the impact assessment methods employed (*Product Environmental Footprint (PEF) Guide*).

Consistency

Data that are consistent with these guidelines shall be used throughout the inventory to allow for meaningful comparisons and reproducibility of the outcomes over time. Any deviation from these guidelines shall be reported, justified 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.

Iterative approach

LCA is an iterative technique. The individual phases of an LCA use results of the other phases. The iterative approach within and between the phases contributes to the comprehensiveness and consistency of the study and the reported results (ISO 14040:2006, 4.1.5).

Transparency

"Due to the inherent complexity in LCA, transparency is an important guiding principle in executing LCAs, in order to ensure a proper interpretation of the results" (ISO 14040:2006, 4.1.6).

Priority of scientific approach

"Decisions within an LCA are preferably based on natural science. If this is not possible, other scientific approaches (e.g. from social and economic sciences) may be used or international conventions may be referred to. If neither a scientific basis exists nor a justification based on other scientific approaches or international conventions is possible, then, as appropriate, decisions may be based on value choices" (ISO 14040:2006, 4.1.8).

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 FAO, 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 resources 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 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 for 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 LCA and livestock supply chains.

The benefit of a sector-specific approach is that it gives guidance on the application of LCA 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 feed 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 LCA of environmental impacts from feed supply chains; and
- provide guidance as to future work needed to improve the guidelines and encourage greater uptake of LCA 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 Manufacturers' Federation. The draft guidelines 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 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 avoid the unnecessary confusion and duplication of work that might be caused by the development of potentially competing standards or approaches. The review also followed established procedures set by the overarching international guidance sources listed in Section 4.3.

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. After the evaluation, it was concluded that no existing approach or study set out a full comprehensive methodology for quantifying environmental performance across the supply chain and consequently that the TAG would need to undertake further work 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. Because there is not currently a mechanism is in place to ensure such review, users are invited to visit the LEAP website (www.fao.org/partnerships/leap) for the latest version.

6. Background information on feed supply chains

6.1 BACKGROUND AND CONTEXT

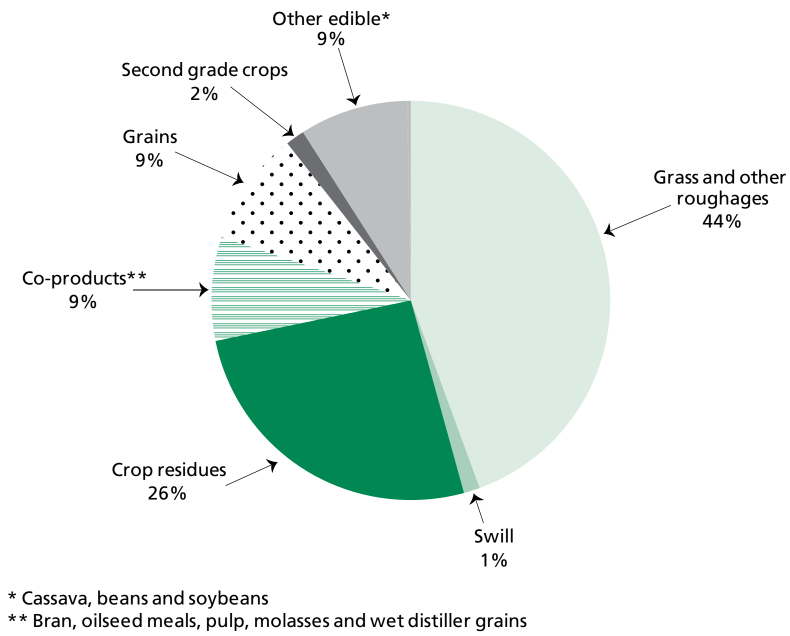
The feed industry is a complex and very dynamic part of the agricultural industry. The last few years have been witness to rapid dietary changes, with an increase worldwide in the demand for animal protein, including meat, dairy products and eggs. One consequence of this demand-led transition in the 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 an ever-changing environment, (including climate change and GHG 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 crop production, 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 species that feed mainly on roughages, such as grass, leaves and forage feedstuffs; and monogastric species that depend largely on feed materials from crop production, such as grains, oil crops and household waste. 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 tonnes compared with 1.4 billion tonnes for 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).

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 complexes 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

Figure 3
Feed utilization by the livestock sector, 2005



Source: FAO *Global Livestock Environmental Assessment Model (GLEAM) (Gerber et al., 2013).*

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 in mixed livestock systems, which are where the majority of ruminant livestock (73 percent) are raised, 69 percent of the animal feed supply comes from 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. As a result, crop production and specialized feed processing plants have emerged to ensure a steady supply of high quality 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 include natural pastures, shrubs, crop residues, household waste and feed from forested areas. 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 GHGs in the life cycle of livestock supply chains. Beside its contribution to climate change, the feed supply chain contributes to other impacts, such as eutrophication, acidification and fossil energy use. Globally, GHG emissions from the production, processing and transport of feed account for about 45 percent of sector emissions (Gerber *et al*., 2013).

Feed production for pork and chicken supply chains contributes 47 percent and 57 percent of emissions, respectively (MacLeod *et al*., 2013). For cattle, small ruminants and buffalo, feed production accounts for 36 percent, 36 percent and 28 percent, respectively, of the total emissions (Opio *et al*., 2013). In ruminant production systems, methane from feed digestion is the largest contributor of GHG emissions.

Fossil carbon dioxide (CO_2) and nitrous oxide (N_2O) are the dominant GHGs emitted in animal feed production. The fertilization of feed crops and the deposition of manure on pastures generate substantial amounts of nitrous oxide emissions, together representing about half of the emissions from feed (one-quarter of the sector's overall emissions). Carbon dioxide emissions result 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 nitrogen fertilizer. In the post-farm stages, carbon dioxide 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 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, resulting in considerable losses of biodiversity. In addition, land use and land-use change account for a large amount of GHG emissions in animal feed production.

About one-quarter of the emissions related to the feed supply chain (about 9 percent of the livestock sector's emissions) are associated with 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. These quality losses constitute the ecological damage from land-use change.

Land use for animal feed production can also have a positive influence on the carbon balance, as the soil acts as a carbon sink instead of as a source of emissions (e.g. deforestation). 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, the way the land is used 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: 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, are considered as feed ingredient in these guidelines. However, detailed guidance regarding the production of feed additives is outside the scope of these guidelines. The only guidance provided will be that on 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 and
- 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 users to utilize only those modules that are relevant to the supply chain they are analysing.

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; 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

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. *This 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 a 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.*

feed chain are 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 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 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

Figure 4
Modular scheme of feed production chains

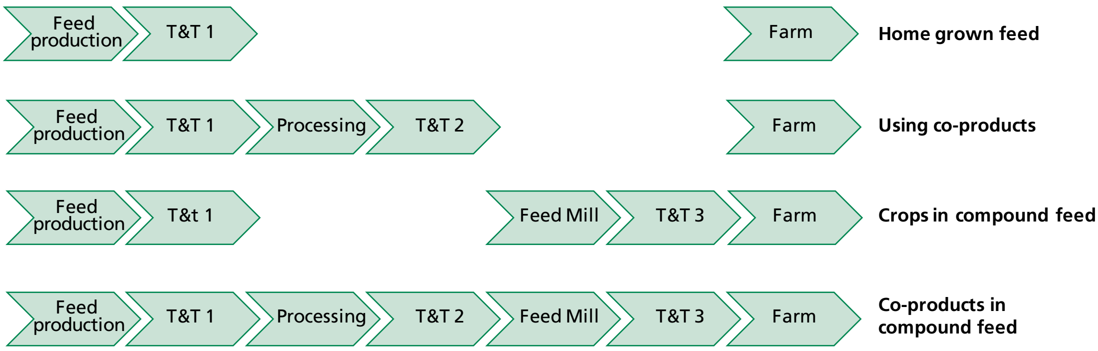
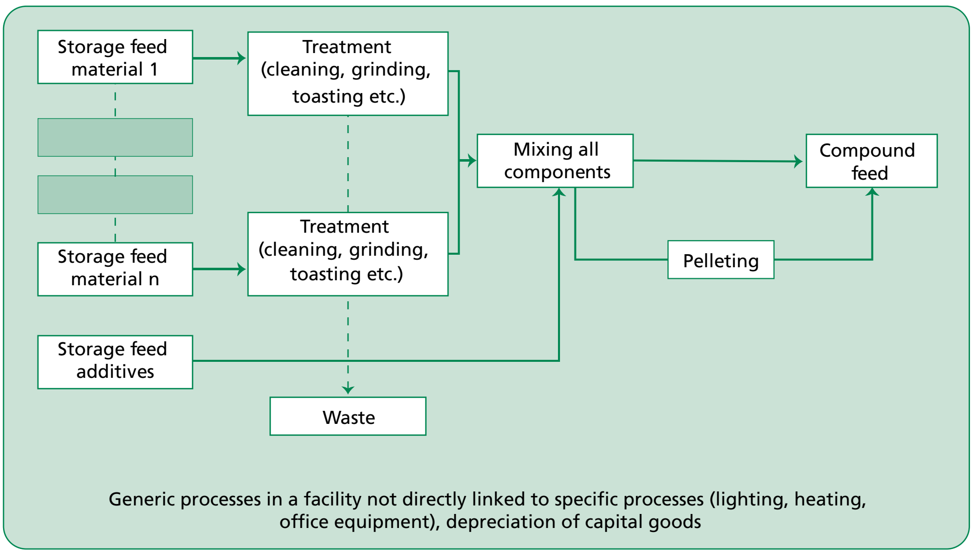


Figure 5
Production process of compound feed



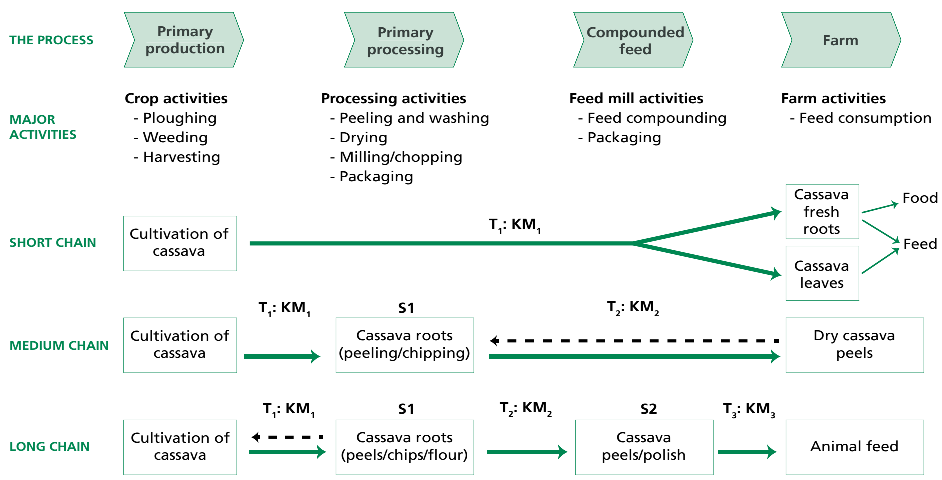
grain with no resulting co-products. Additionally, crop and animal products can be processed into several co-products that are used for food, feed and, in some cases, in other non-food sectors (e.g. vegetable oil extraction from oil crops). In other situations, residues from industrial processes, such as sugar production, bio-fuel production, vegetable and fruit processing, may be used as feed after further processing.

- **Primary crops used in compound feed** include 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

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 (often by tricycles or trucks) with a distance ($KM_{1,\,2}$) of approximately 1 to 5 km.*

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, i.e. 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 the United Republic of 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 for their animals. This mobile system of seasonal and cyclical migration has been practised for decades. The family uses no input for 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 household 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. They 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 and moved 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 animals from their 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.

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).

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

8. Goal and scope definition

8.1 GOAL OF THE LCA STUDY

The first step when initiating an LCA is to clearly set the goal or statement of purpose. This statement describes the goal pursued and the intended use of results. Numerous reasons for performing an LCA exist. LCAs can be used, for example, to serve the goal of GHG emission management by determining the carbon footprint of products and understanding the GHG emission hotspots to prioritize emissions-reduction opportunities along supply chains. However, LCAs can go beyond a carbon footprint and include other environmental impact categories, such as eutrophication, and provide detailed information on a product's environmental performance. They can also serve performance. tracking goals and set progress and improvement targets. LCAs could also be used to support reporting on the environmental impacts of products. However these guidelines are not intended for the comparison of products or labelling of environmental performance.

It is of paramount importance that the goal and scope be given careful consideration because these decisions define the overall context of the study. A clearly articulated goal helps ensure that aims, methods and results are aligned. For example, fully quantitative studies will be required for benchmarking or reporting, but somewhat less rigor may be required for hotspot analysis.

Interpretation is an iterative process occurring at all steps of the LCA and ensuring that calculation approaches and data match the goal of the study (Figure 1 and Section 12). Interpretation includes completeness checks, sensitivity checks, consistency checks and uncertainty analyses. The conclusions (reported or not) drawn from the results and their interpretation shall be strictly consistent with the goal and scope of the study.

Seven aspects shall be addressed and documented during the goal definition (*ILCD Handbook*):

1. subject of the analysis and key properties of the assessed system: organization, location(s), dimensions, products, sector and position in the value chain;
2. purpose for performing the study and decision context;
3. intended use of the results: will the results be used internally for decision making or shared externally with third parties?;
4. limitations due to the method, assumptions, and choice of impact categories, particular those related to broad study conclusions associated with exclusion of impact categories;
5. target audience of the results;
6. comparative studies to be disclosed to the public and need for critical review; and
7. commissioner of the study and other relevant stakeholders.

8.2 SCOPE OF THE LCA

The scope is defined in the first phase of an LCA, as an iterative process with the goal definition. It states the depth and breadth of the study. The scope shall identify the product system or 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 products, the scope of the study may need to be modified as information is collected, to reflect data availability and techniques or tools for filling data gaps. Specific guidance is provided in the subsequent sections. It is also recognized that the scope definition will affect the data collection for the LCI, as described in more detail in Section 10.1.

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 A.2 on feed characteristics.

The feed characteristics should 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).

But this is not always easy. For example, where feed is immediately ingested by a grazing animal, yields are often not known. 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, Small Ruminants and Large 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 provides multiple harvests per year (e.g. two to three cuts of alfalfa or grass). In multiple cropping systems, two or three complete production cycles of sowing and harvesting may also be completed each year. 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 and include 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 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.

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 inputs of nitrogen from manure and synthetic fertilizers; in the downstream stages, energy use. 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. As there is no ownership or land tenure, little information about grass production is available. However, it is well known that inputs to communal pastures are often nil or close to nil.

8.4.2 System boundaries of the feed production stage

The feed production stage encompasses plant-based materials derived from crop cultivation, non-plant materials mainly of animal origin (dairy and slaughter products, fish from aquaculture and wild catch) and materials of non-biogenic origin. Upstream and downstream system boundaries for 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. For multiple harvests per year of the same crop, it can be decided to set the time boundary between two consecutive growing seasons (years). However, when the user wants to go into more detail, it can be considered that the time boundary is set between two production cycles of the same crop. Then the boundary will

Table 1: Upstream and downstream boundaries for feed materials

Input material	Upstream boundary	Downstream boundary
Plant origin	Inputs from unmanaged nature, measured in such a way that that the system maintains mass balance, i.e. including all materials represented in the system outputs	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

be set at the moment when the crop or harvest (of the same crop) has been removed and activities for the new crop or harvest (of the same crop) will start. All emissions related to activities for residues of the previous crop or harvest will be allocated to that previous crop or harvest. More details about time boundaries are given in Section 8.4.9.

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 upstream 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:

- feed production stage;
- 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 systems where feed utilization by the animal takes place at the feed production site itself. In this case, the distinction is artificial. However, this distinction is functional for developing 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).

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

Storage shall only be incorporated into the analysis if it is the responsibility of an entity external 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.

8.4.7 Criteria for system boundary

Material system boundaries: A flow diagram of all assessed processes should be drawn that indicates where processes were cut off. For the main transformation steps within the system boundary, it is recommended that a material flow diagram is produced and used to account for all of the material flows.

Spatial system boundaries: The LCA of animal feeds shall cover the cradle-to-animal-mouth stage for all feed sources, including raw materials, inputs, production, harvesting, storage, loss and feeding. A feed LCA 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

LCA requires tremendous amounts of data and information. Managing this information is an important aspect of performing LCAs, and all projects have limited resources for data collection. In principle, all LCA practitioners attempt to include all relevant exchanges in the inventory. Some exchanges are clearly more important in their relative contribution to the impact categories of the study, and significant effort is required to reduce the uncertainty associated with these exchanges. In determining whether or not to expend significant project resources to reduce the uncertainty of small flows, cut-off criteria may be adopted (Section 8.2).

Exchanges that contribute less than 1 percent of mass or energy flow may be cut off from further evaluation, but should not be excluded from the inventory. Larger thresholds shall be explicitly documented and justified by the project goal and scope definition. A minimum of 95 percent of the impact for each category shall be accounted for. Inputs to the system that contribute less than 1 per cent of the environmental significance for a specific unit process (activity) in the system can be included with an estimate from a scoping analysis (Section 8.2). The scoping analysis can also provide an estimate of the total environmental impact to evaluate against the 95 percent minimum.

For some exchanges that have small mass or energy contributions there still may be a significant impact in one of the environmental categories. Additional effort should be expended to reduce the uncertainty associated with these flows. Lack of knowledge regarding the existence of exchanges that are relevant for a particular system is not considered a cut-off issue but rather a modelling mistake. The application of cut-off criteria in an LCA is not intended to support the exclusion of known exchanges, it is intended to help guide the expenditure of resources towards the reduction of uncertainty associated with those exchanges that matter the most in the system.

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. The effect of some related inputs and activities, are

not necessarily seen immediately, i.e. in the same year in which the activities take place or when the input is applied. They inputs are released and utilized over a longer period of time. Section 9 on allocation and section 11.2 on cultivation 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 and machinery) with a lifetime greater than one year may be excluded in the LCI. All consumables and at least those capital goods whose life span is below one year should be included for assessment, unless it falls below the 1 percent cut-off threshold noted in Section 8.4.3.

8.4.11 Ancillary activities

Emissions from ancillary inputs (e.g. servicing, employee's 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 part of a scoping analysis.

8.4.12 Delayed emissions

The PAS 2050:2011 approach is recommended[1], where it is not necessary to visualize all biogenic carbon flows. All emissions of biogenic carbon associated with the cultivation stage of products are assumed to occur within the time boundary for data, generally of one (PAS 2050:2011 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, if there is a reduction in GHG emissions associated with a process or product that results from the removal of, or preventing the release of, GHG emissions in life cycle of the product, this shall be included in the inventory. If reported, details for the methodology and assumptions need to be clearly documented.

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). Among others, these include: climate change, acidification, eutrophication, land occupation and fossil energy use (Table 3). For climate change, including climate change from land-use change, land occupation and fossil energy use, the recommended method should be applied. For the other impact categories, Table 3 provides recommendations of possible methods that are

[1] Where not arising from land-use change (5.5), changes in the carbon content of soils, including both emissions and removals, shall be excluded from the assessment of GHG emissions under PAS 2050:2011.

Table 3: Examples of 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) over a 100 year time horizon.	Forster *et al.,* 2006 (Table 2.14)
Climate change from direct land-use change to be reported separately	kg CO_2 equivalent	Bern model - global warming potentials over a 100 year time horizon. Inventory data for area associated with land use change per land occupation type and related GHG emission are based on two methods: 20 years depreciation of historical land use change (PAS 2050-1:2012, BSI, 2012) global marginal annual land-use change (Vellinga *et al.*,2012)	PAS 2050-1:2012 (BSI, 2012) Vellinga *et al.*,2012, see Appendix 1
Fossil energy use	MJ (higher heating value)	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 ReCiP*e* and Guinée *et al.* (2002), fossil energy use is either a separate impact category or part of a larger category such as abiotic depletion.
Land occupation	m^2 * year per land occupation 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*., 2009), 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*., 2009), ILCD or a regional specific impact assessment method

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.

9. Multi-functional processes and allocation

9.1 GENERAL PRINCIPLES

The ISO 14044:2006 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.

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

a) 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

b) 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. In other words i.e. they should reflect the way in which the inputs and outputs are affected 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.

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 14044:2006).

9.2 A DECISION TREE TO GUIDE METHODOLOGY CHOICES

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

1. the combined, complex and 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.

The following sections will elaborate on the recommended default methods contained in these guidelines based on attributional LCA.

9.2.1 Allocation at farms and factories

This section also applies to industrial fishing for fishmeal and fish oil. The ISO step-by-step approach is applied on three aggregate stages (Figure 7):

- Stage 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).
- Stage 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).
- Stage 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 include the crop fields in an arable farm, or the production lines in a manufacturing 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. And finally, it is necessary to identify the market supplied by each co-product, and the functional unit of the product on this market. Grouping can also be made of co-products from the same production unit when they have the same functional unit and the downstream application is not affected by the differences between the products. Figure 7 presents the detailed decision tree and principles recommended in the application of the allocation process of feed materials. Examples on the application of the decision tree are provided in Section 11 on LCI.

Stage 1: Avoid allocation by subdividing processing system

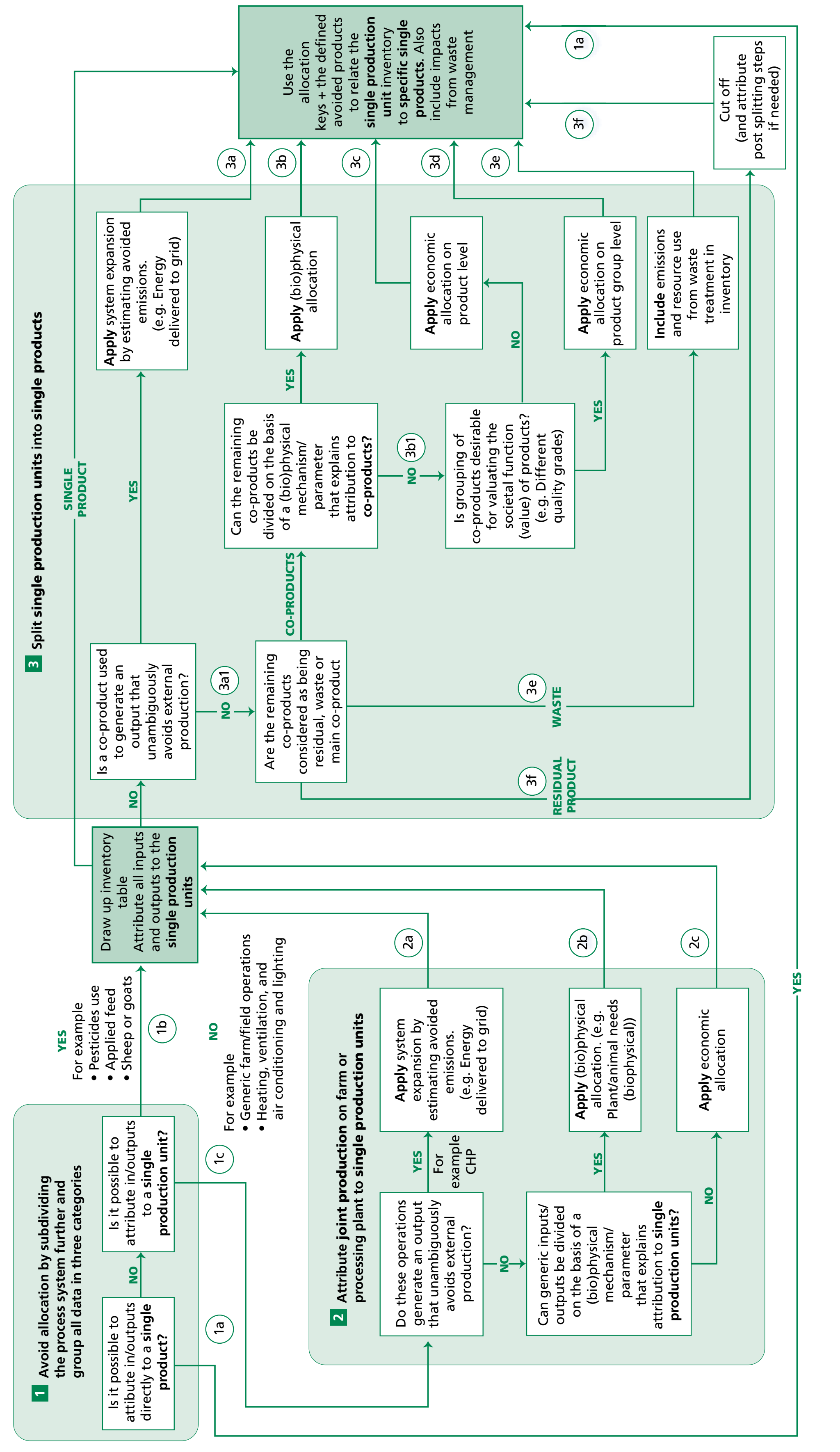
'ISO step 1a subdivision', all processes and activities of a farm/factory are divided into three categories:

flow 1.a. Inputs/activities that <u>can be directly assigned to a single co-product</u> should be assigned to that co-product (e.g. storage and drying operations that can be assigned to one specific production only, or drying of oil seed meals after separation).

flow 1.b. Inputs/activities that <u>can be assigned to production units,</u> which may provide single or multiple co-products (e.g. input of pesticides, fertilizers, for corn are assigned to the 'corn production unit' of a farm with multiple crops; energy inputs of field operations for a specific crop at an multi-crop farm; feed intake for a specific animal type at a multi-type-animal farm; or energy inputs in a (pre) separation process, such as crushing or milling). It should be noted that lime, fertilizers and soil improvement products or operations that are applied to, or performed for, a specific crop may reduce the need for such inputs to other crops, and these inputs may therefore be subdivided in proportion to the requirements of each crop for the specific inputs.

Figure 7

The decision tree for allocation in the feed production chain



flow 1.c Inputs/activities of a generic nature in a farm or factory. Some general inputs, such as internal transport, capital goods and office overheads, that cannot be directly attributed to specific production units, but are nevertheless necessary for the operation of all production units, can normally be assigned to each production unit in proportion to the causal relationship that determines increased need for each input, such as weight, volume, or area (transport, roads, buildings) or revenue (office and accounting).

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.

Stage 2: Attribute combined production to separate production units.

System expansion: ISO step 1b: As part of the harmonization effort behind these guidelines, the range of allocation options in application of LCA is restricted to feed supply chains, and exclude the application of system expansion by means of substitution. Furthermore, its use is limited to situations in which "expanding the product system to include the additional functions related to the co-products" is acceptable within the goal and scope of the study (ISO14044:2006). The alternative, consequential use of system expansion using an avoided burden calculated through substitution is not compliant with these guidelines.

Allocation: ISO step 2: When system expansion to include additional functions within the scope of analysis is not possible, the second question is whether a physical allocation is possible. 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, such as 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 (e.g. manure and other organic fertilizers that provide minerals to the subsequent crops after being applied to the initial crop).
c. complex multiple cropping systems where plants are cultivated alongside one another in an intercropping system, i.e. in a single field.

Allocation: ISO step 3: 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 (e.g. nitrogen, phosphorus or potassium), if sufficient information is available. Otherwise, allocation shall be based on the economic value of the crop-production units, except for crop rotations in open field cultivation that is area-based (flow 2b, Figure 7).

Application of organic fertilizers (e.g. animal manure, peat products, compost) in agricultural production systems result in emissions that occur within one year and delayed emissions that occur afterward.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 and should be fully allocated to the crop of application.
- emissions that occur after one year of organic fertilizer application and 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 shall be made on the total area in the allocation by multiplying the area used for sequential cropping by the number of cropping cycles.

9.2.2 Processing

Similar to cultivation, some of the activities in processing cannot be simply assigned to the production units (e.g. climate control, lighting, infrastructure). 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, 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 (flow 2b in Figure 7).

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

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:

- they are sold in the condition as it appears in the process (before drying and other modifications) and contribute very little to the turnover of the company (value of the total flow less than 1 percent); and
- they are included in upstream and production process that produce the output and are not deliberately modified for these outputs.

Co-products[2] classified as residues shall not be considered as 'waste' because they are part of a processing or production process. 'Waste' is material that is destined for disposal of (e.g. incineration and land fill).

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

In most cases, however, there is no 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. For example some products are used for their energy content, while others for their protein content or even specific amino acids.

[2] 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 and potato peels, disposed fruit and vegetables, wet distillers' grain and wet beet pulp). See Section 11.3.5 for a list of co-products considered as residuals in a baseline assumption.

One could thus consider developing a physical allocation rule for each category of feed (e.g. energy-rich, protein-rich). 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. Unless the complex physical relationship can be captured in a physical model, economic allocation is the preferred method, as it seems to provide the best option to allocate the environmental burdens in a consistent manner and on the basis of meaningful relationships. The average economic value of a product should be estimated over 5-year time frame.

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. Often groupings of products that have similar applications is done 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 and 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 different quality apples? In PAS 2050-1:2012 *Assessment of life cycle greenhouse gas emissions from horticultural products* (BSI, 2012), it is recommended not to differentiate beyond a level that exceeds basic functionality and a level that is related exclusively to consumer preferences.

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

9.2.3 Allocation of transport

Since feed raw material and 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 to allocate empty transport (e.g.for when a ship or other means of transport returns empty); 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 provide a best estimate for empty return with a corresponding uncertainty, per the requirement in section 10.4.

Allocation of empty transport kilometers 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.

9.2.4 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 and decomposition of manure in cultivation falls within the system boundaries. At this point, the most important issue is defining the upstream life cycle of manure in ways that are in line with the animal guidelines.

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 LCA. 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, national or sectoral levels. When evaluating the data collection requirements for a 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 a larger scope, such as sectorial 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 and 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 resources used and emissions associated with each life cycle stage included within the defined system boundaries. For processes where the practitioner does not have direct access to primary data (background processes), secondary data can be used. When possible, data collected directly from suppliers should be used for the most relevant products they supply. 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 (e.g. the economic value of products over 5 years).

For agricultural systems, two main differences exist as 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 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 shall 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 study methodology. To clarify the nature of the inventory data, it is useful to differentiate between 'measured' and 'modelled' foreground system LCI data.

The LCA practitioner shall demonstrate that the following aspects in data collection have been taken into consideration when carrying out the assessment (adapted from ISO14044:2006):

1. **representativeness**: qualitative assessment of the degree to which the data set reflects the true population of interest. Representativeness covers the following three dimensions:
   1. *temporal 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;
   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;

sources of the data;

6. **uncertainty** of the information (e.g. data, models and assumptions).

For significant processes, the LCA practitioner shall document data sources, 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 of higher quality are not available or it is impractical to obtain them.

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 the LCI data set creation, including metadata documentation. The data management plan should include (WRI and WBCSD, 2011b, Appendix C):

- 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 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, such as those described by the Database Registry project of the UNEP/SETAC Life Cycle Initiative;
- data presented at conferences or otherwise publicly available (e.g. internet sources); and
- data from industrial studies or reports.

10.2.1 Requirements and guidance for the collection of primary data

In general, primary data shall, to the fullest extent feasible, be collected for all foreground processes and for the main contributing sources of environmental impacts. Foreground 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. For example, if a national-scale evaluation of the feed sector is planned, it is impractical to collect farm-level data from all producers. In these cases, aggregated data from national statistical databases or other sources (e.g. trade organizations) may be used for foreground processes. In every case, clear documentation of the data collection process and data quality documentation should be collected and stated to ensure compatibility with the study goal and the degree of scope shall be incorporated into the report.

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

10.2.2 Requirements and guidance for the collection and use of secondary data

Secondary data refers to life cycle inventory data sets that are generally available from existing third-party databases, government or industry association reports, peer-reviewed literature, or other sources. It 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, LCI for goods and services consumed by the foreground system should be geographically and technically relevant. An assessment of the quality of these data sets (Section 10.3.2) for use in the specific application should be made and included in the documentation of the data quality analysis.

Where primary data are unavailable and where inputs or processes make a minor contribution to total environmental impacts, secondary or default data may be used. However, geographic relevance should be considered. For example, if default data are used for a minor input, such as a pesticide, the source of production should be determined and a transportation component added to the estimated emissions to account for its delivery from site of production to site of use. Similarly, where there is an electricity component related to an input, an electricity emission factor for the country or site of use should be used that accounts for the energy grid mix.

Secondary data should only be used for foreground processes if primary data are unavailable, if the process is not environmentally significant, or if the goal and scope permit secondary data from national databases or equivalent sources. All secondary data shall satisfy the following requirements:

- They shall be as current as possible and collected within the past 5-7 years. However, if only older data is available, documentation of the data quality is necessary and determination of the sensitivity of the study results to these data shall be investigated and reported.
- 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 fulfil the data quality requirements specified in this guide (Section 10.3).
- They should, where available, be sourced following the data sources provided in this guide (e.g. Section 11.2.2) and for animal assessment (Appendices 3 and 4).
- 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.

An assessment of the quality of these datasets for use in the specific application should be made and included in the documentation of the data quality analysis. When secondary data are used, the LCA user shall make explicit reference to the data source.

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 produced 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. Work has been done by the International Feed Industry federation and the European Union Association of Specialty Feed Ingredients. The study report, including the critical review report, is now available upon request for interested stakeholders.

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 organic compounds, such as amino-acids and enzymes, 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.

In addition to the environmental impact of the feed additives, the effect of the additive on animal performance and feed conversion ratio shall be taken into account 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 are 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 data is set to zero, the result is biased towards lower environmental impacts (Huijbregts *et al.*, 2001).

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
AgriBalyse	Database	France	http://www.ademe.fr
European Reference Life Cycle Database (ELCD)	Database (web-based)	European Commission	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 usershttp://www.agri-footprint.com http://www.pre-sustainability.com/
United States Department of Agriculture (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 US. http://www.nrel.gov/lci/
Japan Environmental Management Association for Industry (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 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 (graphical user interface-based) with database	Global	PE International in partnership with Department of Life Cycle Engineering at University of Stuttgart developed GaBi LCA software. Subscription required http://www.gabi-software.com

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, expensive and often not feasible. This section provides additional guidance on filling data gaps with proxy and estimated data, and is primarily targeted at LCA practitioners. Proxy data is never recommended for use in foreground systems as discussed elsewhere in this guidance.

The use of proxy data sets, i.e. LCI data sets that are the most similar to a process or product for which data is available, is common. This technique relies on the practitioner's judgment, and is therefore, arguably, arbitrary (Huijbregts *et al*., 2001). Using the average of several proxy data sets instead of the a single data set has been suggested as a means to reduce uncertainty, as has bridging data gaps by extrapolating from another related data set (Milà i Canals *et al*., 2011). Adapting an energy emission factor for one region to another with a different generation mix is another option. While the 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 to bridge 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 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 impact category considered. When such proxy data are utilized it shall be reported and justified. When possible, an independent peer review of proxy data sets by experts should be sought, especially when they approach the 20 percent cut-off point of overall contribution to each emission factor, as errors in extrapolation at this point can be significant. Panel members should have sufficient expertise to cover the breadth of LCI data that is being developed from proxy data sets.

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 shall 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. It improves the inventory's data content for the proper communication and interpretation of results, and informs 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 temporal representativeness, as well as the completeness and precision of the inventory data. This section describes how 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 temporal), completeness regarding impact category coverage in the inventory, the 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 temporal representativeness. Table 5 presents a summary of selected requirements for data quality. Any deviations from the requirements

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.

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 a detailed uncertainty assessment.

10.3.2 Data quality indicators

Data quality indicators define the standard for the data to be collected. These standards relate to issues such as representativeness, age and system boundaries. During the data collection process, quality of activity data, emission factors, and/or direct emissions data shall be assessed using the data quality indicators.

Data collected from primary sources should be checked for validity by ensuring consistency of units for reporting and conversion, and material balances to ensure that, for example, all incoming materials are accounted in products leaving the processing facility.

Secondary data for background processes can be obtained from different sources, for example, the ecoinvent database. In this situation, the data quality information provided by the database manager should be evaluated to determine if it requires modification for the study underway (e.g. if the use of European electricity grid processes in other geographical areas will increase the uncertainty of those unit processes).

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 (Section 12) and reporting and communication (Section 12.5). The *Greenhouse gas protocol Product life cycle accounting and reporting standard* provides additional guidance on quantitative uncertainty assessment that includes a spreadsheet to assist in the calculations.

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 are 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 percent confidence interval) and an assessment 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 year-to-year variations in weather patterns. This is particularly true for crop yields, but these variations 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 be to capture and identify either seasonal or inter-annual variability in the efficiency of the product system.

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 LCI modelling, including the decisions on which data to collect, depends largely on the goal and scope of the study. The 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 the allocation for different co-products); and aggregating the 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 GHGs (carbon dioxide, nitrous oxide and methane), emissions of ammonia, nitrate, and phosphorus in cultivation, and for many of the combustion processes in all process stages.

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

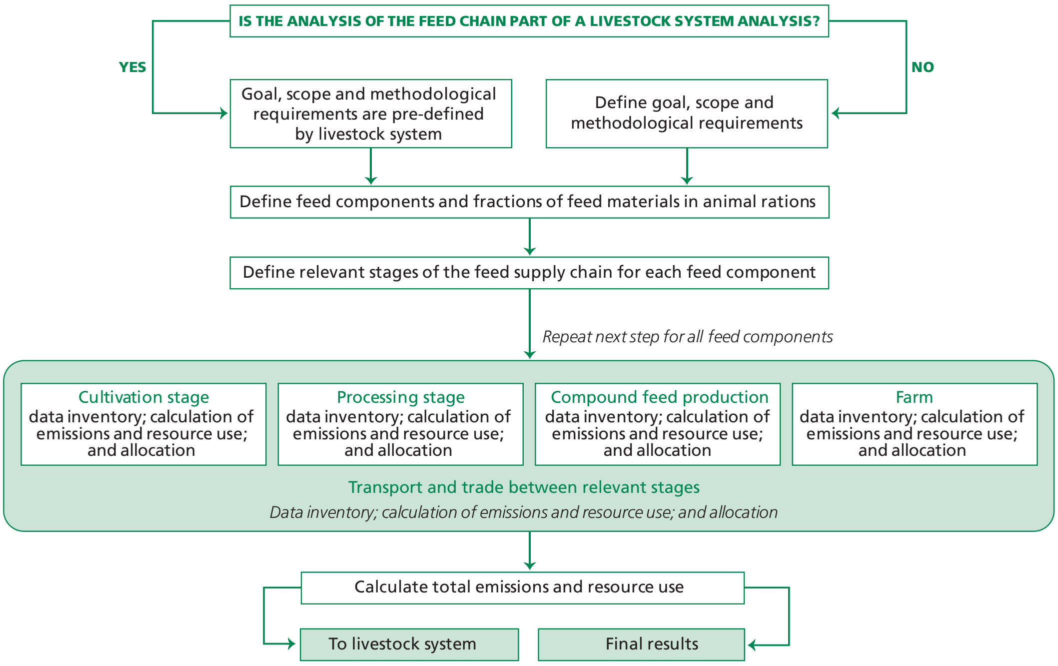
Feed production chains are sometimes long and complex and may be limited to some specific stages. This section describes the inventory process for all stages and situations. For example, in extensive farming systems, using low external inputs and relying on home grown feed, only a specific selection of the guidelines has to be used. A step-by-step 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 the goal, scope and methodology (e.g. system boundaries and impacts) needs to be defined.

The goal and scope of the analysis affects data collection and the quality of the required data. Primary data can be easily obtained for crop production, whereas for a sectoral analysis, 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 critical than it is for a study geared at the comparison of farming systems or a study with a benchmarking goal. *The Product Environmental Footprint (PEF) Guide* requires high-quality data in the cases where there is a high contribution to environmental impacts. This, however, is not related to the goal and scope.

Figure 8
Flow chart to analyze the feed supply chain



In cases where 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:

- **The cradle-to-gate stage** encompasses the analysis of the primary production of the feed materials from plant origin.
- **The 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.
- **The 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.

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).

11.2 CRADLE-TO-GATE ASSESSMENT FOR CULTIVATION

11.2.1 Description of the cultivation system

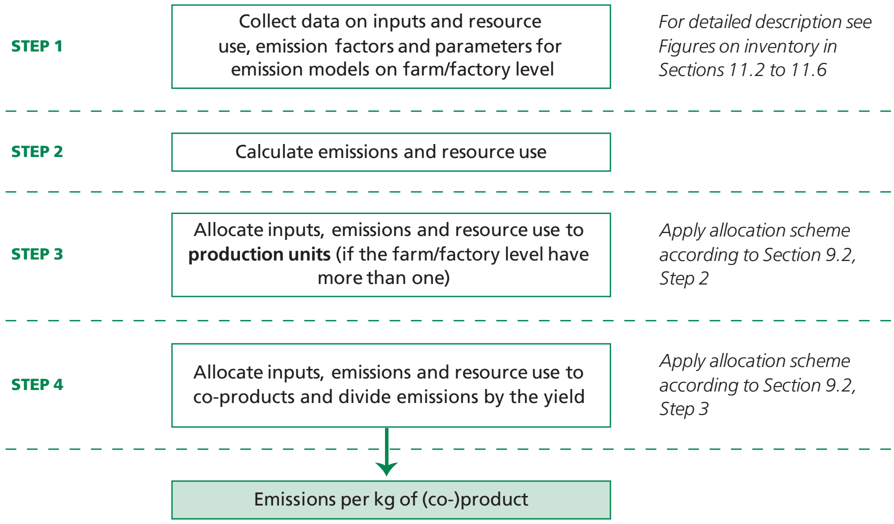
The cultivation system on a farm consists mostly of a number of fields upon which one or more different crops are grown.

Crops can be classified into:

- annual crops with one complete production cycle in one year[3];

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

Figure 9
Steps in the inventory and emissions calculation per stage of the feed production chain



- 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). 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 (e.g. alley cropping, even with combined perennial and annual crops cultivated in one field).

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

Inputs and resources to maintain the production system may take place at the 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, some of the inputs and resources used 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 to the 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, which result in broad variations between production cycles. To deal with these variations, in accordance with clause 7.6 of PAS 2050:2011, 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. This shall be undertaken as set out in points a) to c) below [4][5][6]:

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

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), 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.

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 summarized in Table 7. For example, climate change impacts (GHG emissions) in agriculture can originate from carbon dioxide, nitrous oxide or methane.[7] Emissions for these three gases are associated with the

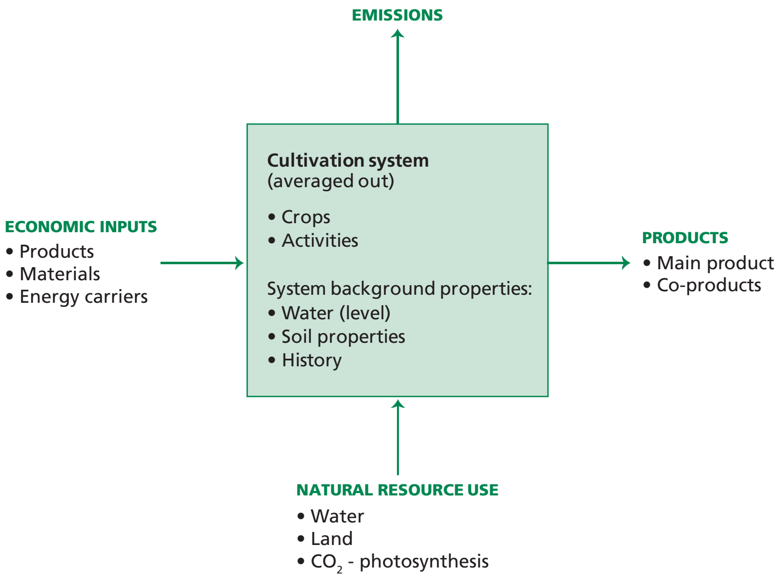
[4] The underlying assumption in the cradle-to-gate GHG emissions assessment of agricultural products is that the inputs and outputs of the cultivation under study are in a 'steady state', which means that all development stages of perennial crops (regardless of the different quantities of inputs and 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).

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

[6] 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-year average.

[7] Cooling agents can also 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 10
An overview of the cultivation system and its inputs and outputs



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, all relevant impact categories should be covered. In case of a stand-alone feed chain analysis, other environmental impacts may be relevant and additional emissions shall be calculated as well.

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.

<u>Seed plant material</u>

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.

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	carbon dioxide (CO_2)	Production and use of fossil materials (fuels, lime, carbon in Urea, etc.)
		Land use change: carbon dioxide from conversion of (previous) above ground or below ground biomass
		Land use: carbon from soil due to soil management
		Peat soils: carbon from soil due to ground water management
	nitrous oxide (N_2O)	Fertilizer production and application, from manure application, from crop residues
		Crop residues
		Burning crop residues
		Mineralization of organic matter
		Land use change
	methane (CH_4)	Burning of biomass
		Anaerobic soil processes (e.g. rice)
		Anaerobic processes of waste treatment on farms (a.o. palm oil effluent)
		Upstream processes
Acidification	ammonia (NH_3)	Nitrogen application (a fraction that volatizes)
	sulphur oxides (SOX)	Upstream processes, mostly fuel combustion
	nitrogen oxides (NO_x)	Upstream processes, mostly fuel combustion
Eutrophication	ammonia (NH_3)	Nitrogen application (a fraction that volatizes)
	nitrogen oxides (NO_x)	Upstream processes, mostly fuel combustion
	nitrogen (N) to soil	Fertilizer and manure application
	N to water	Fertilizer and manure application
	phosphorus (P) to water	Fertilizer and manure application
Fossil energy use	MJ (high heating value)	Use of all kinds of fossil fuels
Land occupation	M2	Land requirement for all kind of activities

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

- the amount of seeds or plant material used, expressed as kg per ha; 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 simplest 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).

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 tonne-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 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 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 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 annual input	• If 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 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 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

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/tonne or cubic metre) and the application rate of manure (cubic metre or tonne/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 nitrogen to phosphorus ratio, although this is highly variable around the world. In this situation, the most appropriate method is to calculate phosphorus excretion by assessing intake and retention in milk, eggs and other products.

Data on the method of manure application should be collected, if this is required by the applied models used for calculation of nitrogen 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 nitrous oxide, ammonia and nitrogen oxide 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.

Nitrogen from synthetic fertilizer

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

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 nitrous oxide, ammonia and nitrogen oxide 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.

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 phosphorus pentoxide (P_2O_5) or potassium oxide (K_2O) per ha, 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 may 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.

Application of lime

Activity data collection: Data shall be collected on the application rate of lime, expressed as kg calcium carbonate ($CaCO_3$) per ha. 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 lime shall be assigned to the crops in the cropping system in proportion to their pH requirement relative to the situation before liming. This may imply that the lime is assigned to only one or a few of the crops. The application of lime is of special importance for climate change because carbon dioxide is released after the application of lime. If the calcium carbonate is from fossil origin, 1 kg application of calcium carbonate yields 0.48 kg of carbon dioxide. Liming can also take place with co-products or residues (e.g. co- products 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 carbon dioxide 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.

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 carbon/nitrogen 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 (carbon dioxide and nitrous oxide). Both are released during the decomposition of peat. Emission factors for carbon dioxide and nitrous oxide 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.

Application of pesticides

Activity data collection: Data shall be collected on the application rate of pesticides, expressed as kg active ingredient per ha. 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 (carbon dioxide emissions). 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 eco-toxicity and biodiversity. These impacts are not included in the current guidelines.

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, natural gas and heavy fuel oil. In addition, fuels such as coal and peat can be used. Emissions arise primarily from combustion of these fuels. In addition to the combustion emissions, other emissions result from the production and transportation of these types of fuels, the production of capital goods and fthe 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.*, 2011).

Activity data collection: Data shall be collected regarding direct fuel use, the amount used in the process per type of fuel and on the 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 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.

Machine use

When machines are used, the total fuel consumption shall be calculated. However, the fuel use shall be counted once, see above. 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 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 where there is a high level of mechanization. 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 the production and maintenance of machines and tractors are related to the weight and type of machine and tractor and should be collected from databases.

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 kilowatt-hours (kWh), 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.

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 important contributions of carbon and nitrogen to the soil, improving 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 and methane. Emissions of crop residues produced by the field for other purposes, such as feed, biofuels and bedding, 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 nitrogen per ha. 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 ha; 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: Carbon dioxide emissions from burning are not to be taken into account, as they belong to the short carbon cycle. Emission factors for methane, nitrous oxide and nitrogen oxides shall be based on the IPCC (2006, Volume 5, Chapter 2), unless specific national emission factors are available.

Land-use type and land 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 a number of 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. Carbon dioxide emissions from soil organic matter are known to contribute to climate change. However, changes in management can lead to changes in soil organic matter. 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 and
- 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. For 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 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.

Activity data collection: Data shall be collected on the 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 ISO/TS 14067:2013 and PAS 2050:2011 state that land-use emissions do not need to be calculated. However, in developing these guidelines, it was 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 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 4, Chapter 2).

- The soil carbon models used in the assessment shall have been published in peer-reviewed scientific papers and have passed through a validation procedure.
- 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 Appendix 3 on Land-Use Emissions, which is valid for western European/temperate conditions.
- Land-use emissions shall be reported separately.

Land-use type and land 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).

Soil type

Organic soils will decay when they are drained and used for agriculture. 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 4.

Land-use change

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 carbon dioxide[8] 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, which are related to the many processes and stakeholders 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 consensus is that land-use change emissions should be reported separately (e.g. ISO/TS 14067:2013 and PAS 2050:2011).

Recognizing the ongoing debate and need for further methodological development, these guidelines recommend estimating land-use change using the *ENVIFOOD Protocol* adapting the PAS 2050-1:2012 (BSI, 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 modified by Vellinga *et al.* (2012), which is globally orientated. The comparative analysis shall be done for feed material other than grass from natural rangelands[9], since the feed products from these lands would not enter in the global market.

The *ENVIFOOD Protocol* and PAS 2050:2011: 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 land-use change 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. PAS 2050-1:2012 (BSI, 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 2050-1:2012 (BSI, 2012), a slight modification on the *ENVIFOOD Protocol*, and can be summarized into a four-step approach:

- Has cropland expanded in the country?
- If so, has the crop under assessment expanded?
- If so, how much of total cropland expansion was into grassland and into forest land, respectively? And finally

[8] Land-use change causes multiple GHG emissions (carbon dioxide, nitrous oxide and methane) 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 carbon dioxide and nitrous oxide. In the tools provided for these calculations, such emissions are converted to carbon dioxide-equivalents.

[9] 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 (SRM, 1989).

- How much of forest and grassland land-use change 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, (currently available at www.blonkconsultants.nl), which has been reviewed and approved by the World Resources Institute, has been developed to support the estimates of land-use change emissions using the the PAS 2050-1:2012 (BSI, 2012) and *ENVIFOOD Protocol* approach.

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 (see above for the calculation in each of the producing countries).

The global average method

This 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; Vellinga *et al.*, 2012). This is especially the case for market-oriented agriculture commodity production and to a lesser extent to non-commercial agriculture, but 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 gigatonnes, total global land use is 4.89 billion hectares (FAO, 2013), of which 0.47 billion hectares is rangeland (Henderson *et al.*, 2015).

The average land use change emissions are:

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

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.

BOX 4: Gross and net area of agricultural land

The 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 and growing a crop 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.

When crops are sold, care should be taken to note the amount sold since this can differ from the net yield as a fraction may be lost in storage or a go unsold due to its poor quality, When the amount sold is lower than net yield 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 (e.g. alley cropping, co-products as wheat and straw, 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.

11.2.4 Attributing emissions and resource use to single production units

In the previous section, all inputs, resources and emissions were identified and quantified, and the guidance was provided on the data and emission factors that were required. 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 for 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 the (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.

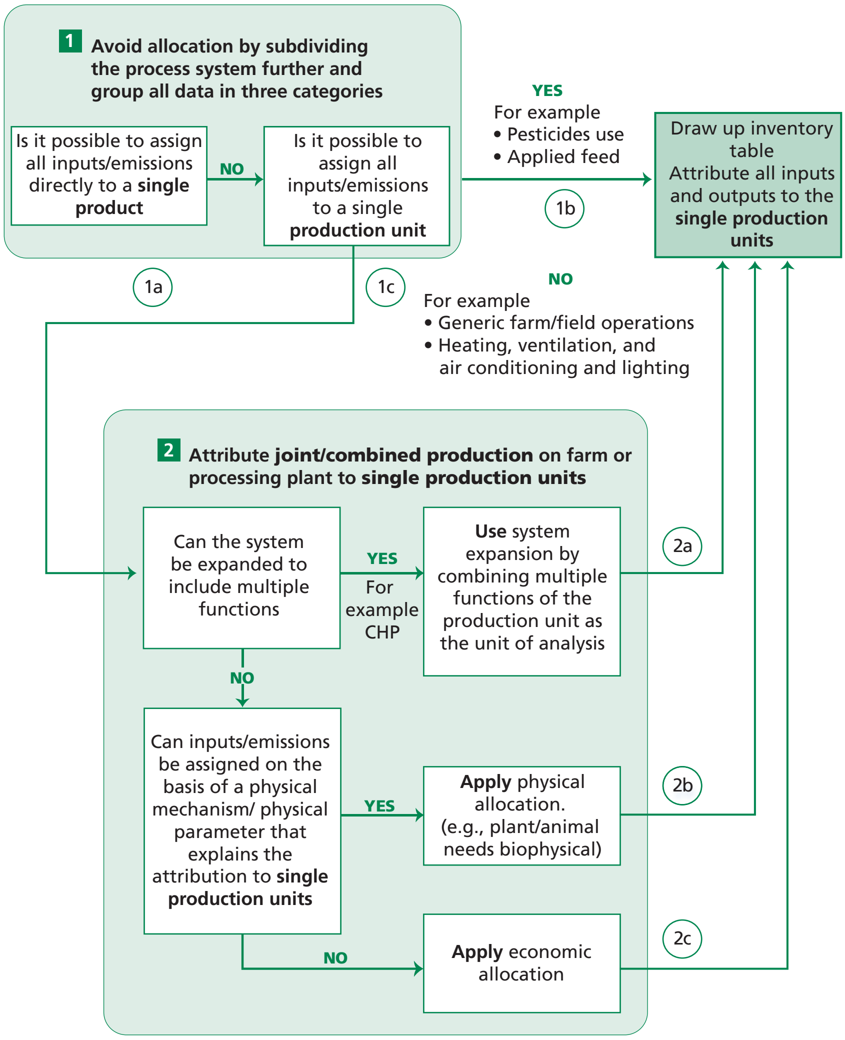
- **Category 1**: (in Box 1, Figure 12): If inputs cannot be attributed to a single product, as they cover multiple fields and years, and cannot be attributed to a single production unit, line 1c has to be used, leading to Box 2, Figure 12, "*The inputs do not unambiguously avoid external production*". 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[10].

Perennial crops are a good examples of a situation in which a combination of generic inputs at the 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, for example, 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.

[10] 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.

When in crop rotations or in perennial crops, a steady state situation is not present, corrections shall 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:

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

where:

$(E,R)_{TotField,Cycle}$ = 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:

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

where:
(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 (e.g. the upstream emissions to produce the fuel)

11.2.5 Attributing emissions and resource use to (co-) Products (allocation)

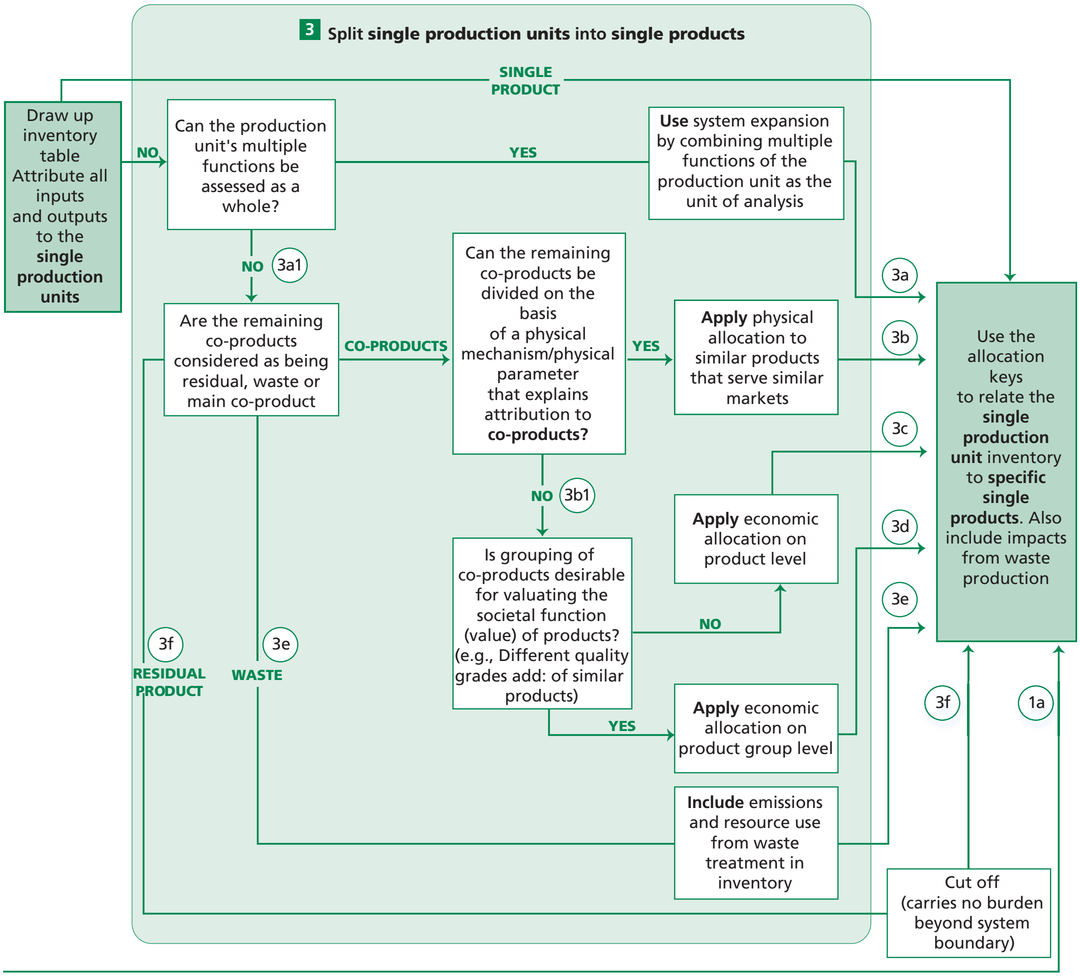
In the previous section, all emissions from inputs and resource use have been attributed to the basic production unit. In crop cultivation, more co-products per crop and more crops per production unit can be generated. This means that the has to be attributed to the different co-products or crops. The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

Situation 1 with only a single product: This is a simple situation and the line 'single product' at the top 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 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.

Figure 13
Attribution to (co-) products



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

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 are 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 5 on the 'push and pull system'.

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

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

where:

$(E,R_{),(co)\text{-}product}$	= emissions and resource use per kg of (co-)product
$(E,R)_{Field,Cycle,(co)\text{-}product}$	= 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
$Alf_{(co)\text{-}product}$	= allocation factor for emissions and resource use of the fraction of the emissions to be attributed to the (co-) product for cultivation
$Y_{(co\text{-})product}$	= the net yield of the (co-)product

<u>How to calculate the allocation factors?</u>

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.

$$Alf_1 = \frac{Y_1 \times w_1}{\Sigma_1^n Y_n \times w_n}$$

where:

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 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.

Box 5: 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, and 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 mine 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 the 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 shall 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 partly reflects the physical causality.

11.2.6 Wild caught fish

Catching wild fish may 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 used for the fishing vessels, 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 tonne of fish landed. There is a wide variation in energy use among fishing vessels. The use of cooling agents can cause GHG emissions, but modern fishing vessels use cooling agents that do not contribute to climate change. Similar to machine use in cultivation, the emissions resulting from the production and maintenance of vessels should be incorporated in attribution. An important aspect of wild

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

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 shall be collected

For 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

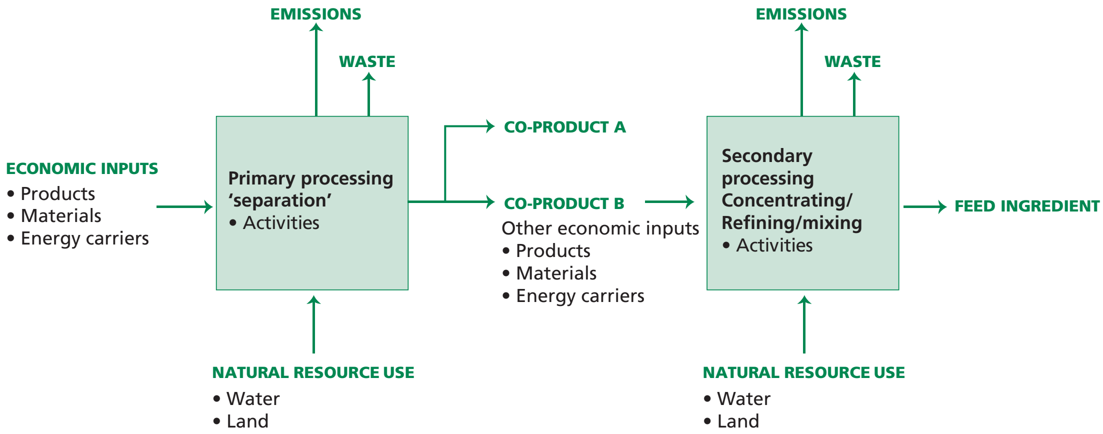
11.3.1 Description of the processing system

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.

Processing inventory tables should be derived from a model of the average operation. This can best be derived by using mass flow balances from 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 that may affect the energy efficiency of processes and fluctuations in the production/capacity ratio will also 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.

Figure 15
Emissions from and resource use in processing feed raw materials



The second group of upstream emissions and resource use concern the total of upstream emissions of the other inputs, such as fuels and ancillary materials, at the processing stage.

11.3.2 Relevant inputs, resource use and emissions during processing

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

Input products

The input products for the processing plant can be of plant origin, such as wheat, cassava and oilseeds, of animal origin, such as 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 necessary to calculate gross energy.

All exchanges shall be recalculated relative to the reference flow. This is often expressed as per kg or 1 000 kg of input product.

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.

In the case of input products of animal origin, 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).

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*

Storage losses

If the input product is stored before processing, there can be losses due to dissimilation, decay, rodents, fungi and other causes. The amount of input product required shall be corrected for losses, which will result in more emissions and resource use per unit of output product.

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: The amount of input product required shall be corrected for losses, which will result in more emissions and resource use per unit of output product.

Fossil fuels

Data collection on fossil fuels and the emission factors are the same as those described in the cultivation section, sub-heading ‘fossil fuels’.

Electricity

Data collection on electricity and the emission factors are the same as those described in the cultivation section, sub-heading ‘electricity’.

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 measured or calculated.

Activity data collection: Data shall be collected on the ancillary material itself (e.g. chemical name) 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.

Output products

At the processing plant, products are often split in two or more co-products.

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.

Waste and residues

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

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 can 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 GHG. 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

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 of 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.

anaerobic digester and 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).

Treatment and storage of residues

Residues can be very valuable from the point of view of animal nutrition. 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 (e.g. reversed osmosis, heating) 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 LCA practitioners have maximum access to industry information. In practice, this is often not the case, since the practitioners get only limited information on request or, may find themselves 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 input/output analysis (see Input/output analysis at factory level).

An input/output analysis at the 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 input/output analysis provides a particularly good estimate (see Vellinga *et al.*, 2012).

For production residues, such as beet pulp, citrus pulp, spent grain, bread and biscuit leftovers, 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, and product storage.

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. 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 the result of an attribution and allocation process, except in rare cases when a factory produces a single product through the year without any other non-production related activities. 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).

As explained in the Section 9 on allocation, the attribution consists of:

1. assigning inputs and activities (e.g. drying, purification, storage) directly to specific co-products (e.g. beet pulp and soybean meal);
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 and 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 a 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.

Applying the right-hand side of the allocation scheme (Figure 13), the first question is whether the multiple co-product functions of production unit can be assessed as a whole. Therefore, system expansion can be applied by combining multiple functions of the production unit, such as heat, electricity and steam, as the unit of analysis.

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.

When a material is considered a waste (e.g. POME, the waste generated in palm kernel fruit processing, or 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) shall be added to the total emissions calculated in Section 11.3.2.

If a material 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 materials 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 17), 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 shall 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.,* 2012), 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.

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.,* 2012). Applied in a more general sense a classification can be made into three types of residues (Box 6).

Many of these materials are further processed to dry feed materials, then stored and transported. However, depending on the vicinity of animal production, these materials 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.

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 be based on the prices of products at the point of separation if physical allocation is not applicable, in accordance with the decision tree.

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 common simplification is to apply allocation on the basis of an input/output analysis of the overall factory or a group of factories (i.e. the overall input/output process).

Box 6: Examples of residues to which no upstream environmental impacts are allocated

- **wet materials from the food consumer products industry** *that are sold 'wet' to animal farms, such as leftovers from fruit, vegetables and potato processing industry;*
- **wet materials from the agricultural commodity industry***, such as citrus pulp; and*
- **dry materials from the food consumer products industry,** *such as chocolate, dry bakery and biscuit products, bread from bakers.*

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, as differences in processing after separation can cause differences in resource inputs and emissions 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 17 gives example of soybean crushing). Under these conditions, the input/output analysis at factory level gives a good estimate for the more precise allocation method, starting at the specific unit process and including the life cycle steps afterwards.

For the following co products input/output 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 and
- soy protein concentrate production.

Detailed economic allocation

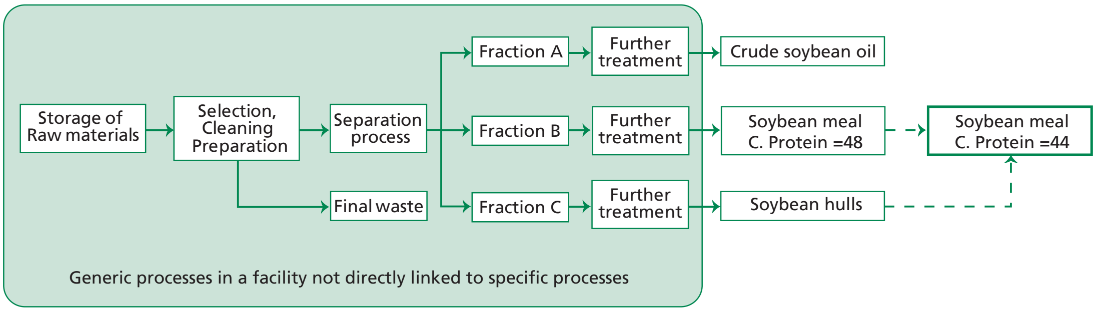
The method described in the previous section should in principle not be applied if there are multiple process steps and where the 'after separation processes' differ significantly among the diverse co-products coming from step 1 in terms of resource inputs, emissions or valorisation (relatively to pre-processing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

This applies, for instance, to wet milling of maize (Figure 18), 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.*, 2012 on recommendations regarding wheat and potato wet milling).

Mass and energy content-based allocation: The two previous sections about input/output analysis and detailed allocation are applicable mainly in the case of economic allocation because intermediate prices are not easy to find.

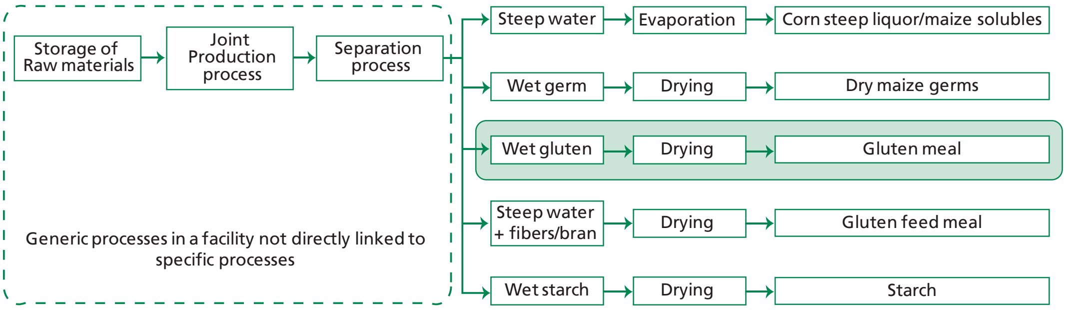
Since the choice of the allocation method can strongly affect the emissions per co-product, a sensitivity assessment applying two alternative allocation methods along with economic allocation are recommended: mass-based and energy content-based allocation.

Figure 17
Co-production for which an input/output based allocation can be applied



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

Figure 18
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).

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, when feedstock carbon is converted to carbon dioxide and consumed in biological processes (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. The caloric value per co-product is determined on the basis of the lower heating value 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, which 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

The default allocation fractions presented in Table 8 should be used as default in feed LCI databases, unless alternative tables containing more detailed information on mass and gross energy of each single material are made available with supporting material, and reviewed by at least a pool of independent technical experts against relevant LEAP guidelines and the interested parties represented in the LEAP Partnership. Similarly, Table 8 should be used as default in feed LCI databases, unless alternative economic values are not submitted to the LEAP Partnership for review.

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 and 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%
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%

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
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)	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%

The general model for attributing inventory data of a production unit to co-products per processing stage is expressed by a formula, 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 the opposite of the processing stage. In compound feed production, many feed materials from primary production (plant, animal and non-biogenic origin) or 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 (e.g. grinding, toasting) before mixing. After the mixing process step, the product can be pelleted or left as a meal (Figure 19). A compound feed factory often produces dozens of different feeds. The composition of these feeds changes through the years, depending on the availability and the prices of raw materials. In addition, compound feeds also change as a result of product developments targeting a better feeding/market performance.

11.4.2 Relevant inputs, resource use and emissions during feed compounding

Figure 20 defines the data and the emission factors that shall be collected at the feed compound stage.

Figure 19
Emissions and resource use in compound feed production

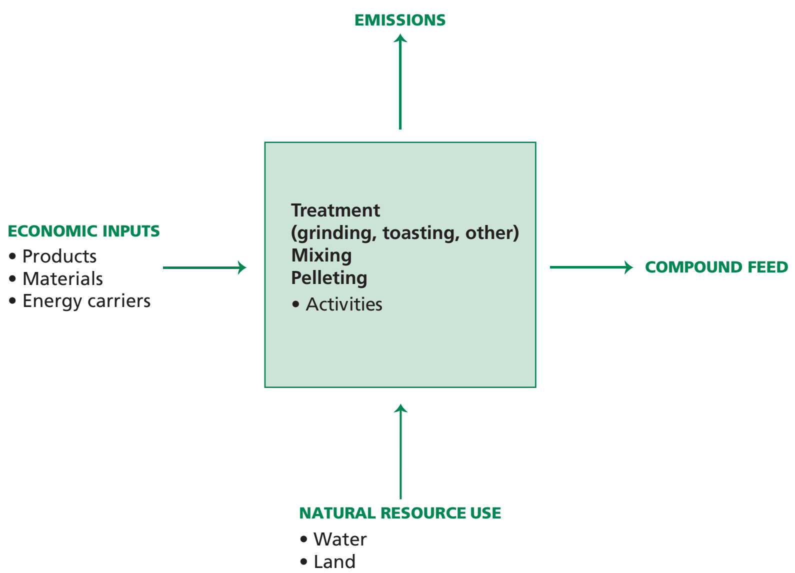


Figure 20
Inventory flow chart for compound feed production

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, m^3, 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

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.

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 (e.g. additives, enzymes, synthetic amino acids). 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.

Storage loss

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

Fossil fuel use

The data collection on fossil fuels and the emission factors are exactly the same as is described in the cultivation section under the 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 depending on the combination of feed components, 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, using best available technology or standard methods.

11.4.3 General model for deriving inventory data

The average model per step is shown in Figure 5 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.

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

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
- $\Sigma(E,R)inp,t$ = 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

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-ANIMAL-MOUTH 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. over a period of time or simply by placing the feeds 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, illustrated in Figure 22, 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 required for putting feed into storage (silage pits, hay stack, silos) and for cooling and heating. Also, ancillary materials such as plastics and additives, are also used. In many cases, conservation processes or damage from insects, rodents and other factors result in 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 is 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 actions. Treatment always requires energy, whether it is 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 or to a total mixed ration. In the case of a partial mixed ration, a number of diverse feeds, but not all, are mixed to form a homogenous product. In a total mixed ration, all animal feeds are mixed. After mixing, either type of ration is often fed immediately to the animal, although intermediate storage can also occur. 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 (including indirect fossil fuels). In many smallholder farms, feeds are mixed and fed to the animals by hand, and there is 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 shall be measured on the basis of the feed allowance. Emissions related to rejected feed also shall be accounted for by the livestock system guidelines.

11.5.2 Relevant emissions and resource use on the farm

Figure 21 defines the data and the emission factors that shall be collected at the farm.

Input products

The number of feeds used at a farm can be very limited. In extensive grazing systems, such as the pastoral systems, phase feeding, 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.

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.

Figure 21

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

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.

Ancillary materials

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

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

Fossil fuel use

The data collection on fossil fuels and the emission factors are exactly the same as is described in the cultivation section under the 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 the LCA practitioner averages out all fossil fuel use over a group of feed products or all of them. This 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.

Machine use

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

Electricity

The data collection on electricity and the emission factors are exactly the same as is described in the cultivation section under the 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.

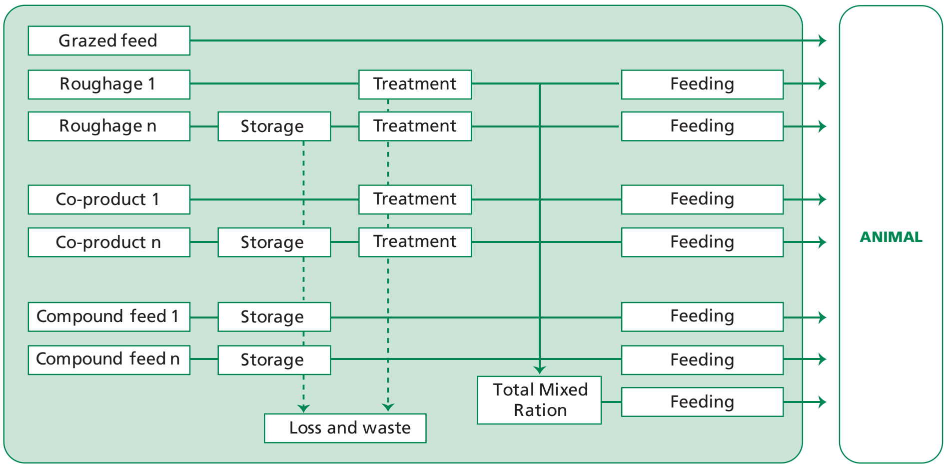
$$(E,R)_R = \sum_{i=1}^{n}(E,R)_n \times kg_n \times (1 - loss)_n^{-1} + (SMTF)_n \text{ Formula (2)}$$

where:

$(E,R)_R$ = Emissions and Resource Use of the animals Ration R

$\Sigma(E,R)_n$ = Emissions and Resource Use of all upstream inputs needed for feed n

Figure 22
Feeding process at the animal farm



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

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

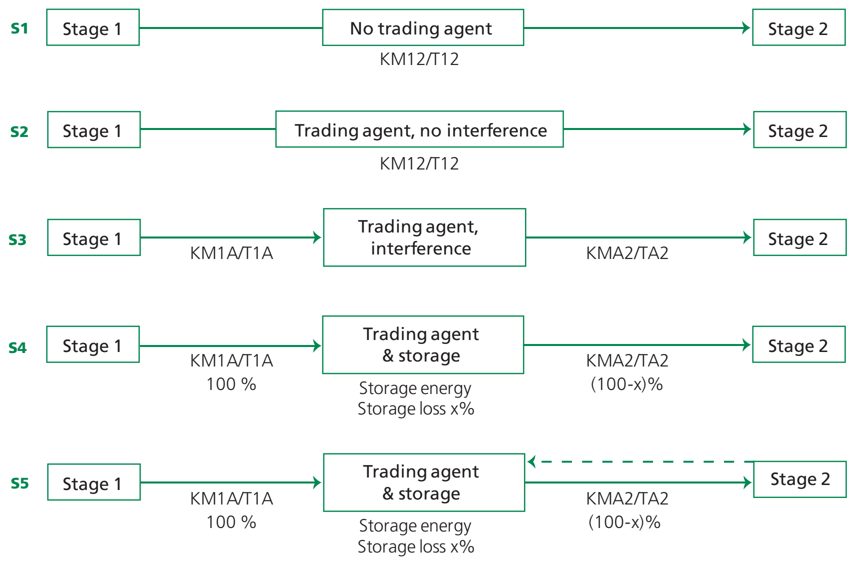
11.6 INTERMEDIATE TRANSPORT AND TRADE

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 kilometers 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 kilometers, inland vessels for canal transport, coastal ships and transcontinental sea ships. The load ranges from 10 kg (human-powered traction) to 30 000 tonnes (sea ships). Air freight 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 labour. In all other cases, transport requires an energy carrier, such as fuels or electricity. Energy resulting from human and animal labour 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 Figure 23 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 in ways that do not affect the transport itself (scenario S2). But when transport is divided into two phases, as depicted in scenario S3, they also can have a larger role. In the case of traders, intermediate storage may take place. The 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 and feed demand is seasonal, (e.g. during the winter).

Figure 23
Transport and trade scenarios



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

This is depicted in scenario S4. In the case of intermediate storage, losses can occur (e.g. from 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 S5 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.

11.6.2 Relevant inputs, resource use and emissions during transport and trade

Transported product

The type of product can provide information about the type of transport required (See Figure 24). 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 tonne of product.

Emission models and LCI data: Not relevant.

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 under the sub-heading ‘fossil fuels’.

Figure 24
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

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 amassed from databases. When secondary data on transport emissions are applied, the emissions from production and maintenance have already been incorporated into the emission factor per tonne per kilometer. The next three steps are required when primary data on fuel use are not present.

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.

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.

Transport data shall be collected (or defined) on:

- 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' kilometers shall be allocated to the transported product.

Emission models and LCI data: Emission factors for 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.

Calculate transport distance

This is done after the start- and endpoint and the means of transport 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 kilometers per means of transport by the emission factor for the transport means and accumulating all emissions for transporting the product from the original start point to the final endpoint.

Storage loss

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

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 under the sub-heading 'fossil fuels'.

Electricity use for storage

The data collection on electricity and the emission factors are exactly the same as described in the cultivation section under the 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
$\Sigma Km_a * (EF/tonkm)_a$	Transport emissions of step a (to the agent) in the transport and trade scheme for the different kinds of transport used
$\Sigma Km_b * (EF/tonkm)_b$	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 tonne per km 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 (*ILCD Handbook*):

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, for example, 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, and 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 processes that contribute the most to the LCIA results.

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 (*ILCD Handbook*):

- **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 LCI model and impact assessment.

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

- **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. Knowledge uncertainty can be reduced by collecting more data, but often limits on resources restrict the breadth and depth of data acquisition. Process uncertainty can be reduced by breaking complex systems into smaller parts or aggregations, but inherent variability cannot be eliminated completely. The LCIA characterization factors that are used to combine the large number of inventory emissions into impacts also introduce uncertainty into the estimation of impacts. In addition, there is bias introduced if the LCI model is missing processes, or otherwise does not represent the modelled system accurately.

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 on 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 proposed changes 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.

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. 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 a number of methodologies, including modelling principles, system boundaries and cut-off criteria, the choice of footprint impact assessment methods and other assumptions related to time, technology and geography. Unlike the LCI and characterization factors, these uncertainties are not amenable to statistical description. However, 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 14044:2006, 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 GHG emissions (Gerber *et al*., 2013). Similar assessments can be made at regional or national scales, provided that there exists a reasonably complete inventory exists of all emissions in that region that contribute to the impact category. Normalization provides an additional degree of insight into those areas in which significant improvement would result in notable advances for for the region in question, and helps decision-makers to focus on supply chain hotspots whose improvement will bring about the greatest relative 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, and explicitly accounting for limitations to robustness, uncertainty and applicability.

Conclusions derived from the study should summarize supply chain hotspots 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, allocation, 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, plausibly founded and strictly relate to the goal of the study. Recommendations shall be given jointly with limitations 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. Where results are required for products throughout the whole life cycle, it is necessary to link this analysis with relevant methods for secondary processing through to consumption and waste stages for example the PCR on textile yarn and thread of natural fibres and man-made filaments or staple fibres (EPD, 2012) and PAS 2395:2014 (BSI, 2014). However, they can be used to identify hotspots 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 minimize the risk of misinterpretation.

The description of the input data and assessment 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:

- possible positive or negative impacts on other (non-GHG) environmental criteria;
- possible positive or negative environmental impacts (e.g. biodiversity, landscape, carbon sequestration); and
- multi-functional outputs other than production (e.g. economic, social, nutritional);

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), and including key elements of goal and scope of the system studied and the main results and recommendations while clearly presenting assumptions and limitations;
- identification of the LCA study, including name, date, responsible organization or researchers, objectives and reasons for the study and intended users;

- goal of the study, its intended applications, targeted audience and 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, its 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; and
- if intended for the public domain, a statement as to 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 for release 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; and
- 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, for example, 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.

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APPENDICES

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

INTRODUCTION

All studies analysing 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 analyse specific situations, whereas sector and regional studies have to develop more general methods to calculate the environmental impact of feed products.

The following studies were selected: Berglund *et al.*, 2009; Capper, Cady and Bauman, 2009; Cederberg, Henriksson and Berglund, 2013; Flysjö, Cederberg and Strid, 2008; Leip *et al.*, 2010; Nijdam, Rood and Westhoek, 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 and Leip, 2012; Whittaker *et al.*, 2013; Zehetmeier *et al.*,2014.

In this document, the common approaches will be noted as well as the 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, Henriksson and Berglund, 2013; van Middelaar *et al.*, 2013; Vellinga *et al.*, 2012; Flysjö, Cederberg and Strid, 2008; Whittaker *et al.*, 2013. Others had a broader scope such as the overall livestock sector in the EU (Leip *et al.*, 2010; Weiss and Leip, 2012) and North America (Nijdam, Rood and Westhoek, 2012); dairy production in the US (Thoma *et al.*, 2013; Capper, Cady and Bauman, 2009) or Germany (Zehetmeier *et al*, 2014); 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, Henriksson and Berglund, 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 A1.1)

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

Table A1.1: Classification of the reviewed literature to overview (sectorial and regional), comparison (between systems, over time) and methodology development

ScopeScope	Literature
Overview	Leip *et al.*, 2010; Weiss and Leip, 2012; Thoma *et al.*, 2013; Vergé *et al.*, 2013; Powell *et al.*, 2013;
Comparison	Capper, Cady and Bauman, 2009; 1944 versus 2007; Thomassen *et al.*, 2008; conventional versus organic; Whittaker *et al.*, 2013: models
Methodology	Berglund *et al.*, 2009; Flysjö, Cederberg and Strid, 2008; Vellinga *et al.*, 2013; Middelaar *et al.*, 2013; Zehetmeier *et al.*, 2014; Cederberg, Henriksson and Berglund, 2013

Vellinga *et al.* (2013). In contrast, Capper, Cady and Bauman (2009) do not mention anything about upstream emissions. Whittaker *et al.* (2013) show that because of different methods of calculation, 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.* (2009), Flysjö, Cederberg and Strid (2008). 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, Cederberg and Strid (2008), Cederberg, Henriksson and Berglund (2013), Thoma *et al.* (2013) and Vellinga *et al.* (2013) explicitly mention economic allocation. Berglund *et al.* (2009) show mass and economic allocation for processing feed materials, whereas Leip *et al.* (2010) use physical allocation based on the nitrogen 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, Rood and Westhoek (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.

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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, detailed nutritional models can be applied to calculate animal requirements, related feed intake, retention and excretion of nutrients.

Table A2.1: Extended list of feed characteristics for different livestock species

Name	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		
Metabolizable energy broilers				X
Metabolizable 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 A2.1: Extended list of feed characteristics for different livestock species *(Cont.)*

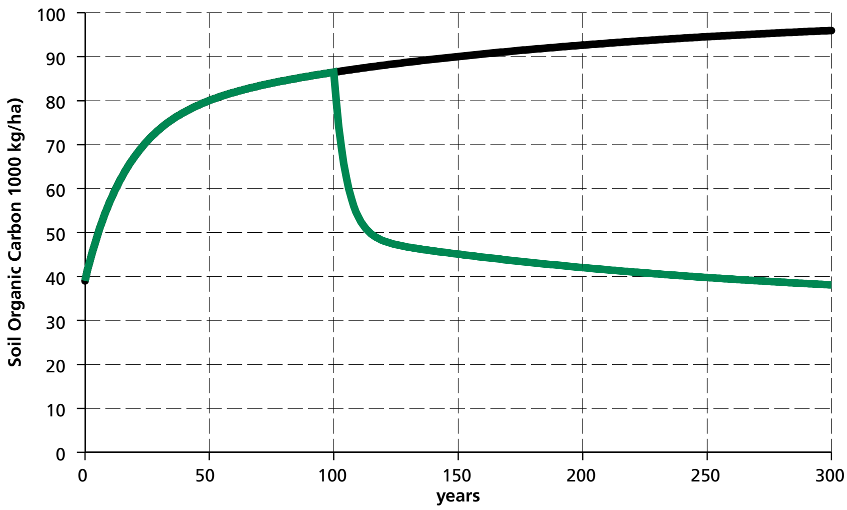
Name English	Ruminants	Pigs	layers	Broilers
Digestible valine, poultry			X	X
Standardized intestine digestible lysine, pigs		X		
Standardized intestine digestible methionine pigs		X		
Standardized intestine digestible cysteine, pigs		X		
Standardized intestine digestible methionine and cysteine, pigs		X		
Standardized intestine digestible threonine, pigs		X		
Standardized intestine digestible tryptophane, pigs		X		
Standardized intestine digestible isoleucine, pigs		X		
Standardized 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; Soussana, Tallec and Blanfort, 2009) and are affected by stocking densities, nitrogen inputs and grassland renovation (Conant *et al.,* 2005; Vellinga, Van den Pol-Van Dasselaar and Kuikman, 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 process (Soussana *et al*., 2007; Soussana, Tallec and Blanfort, 2009). According to the equilibrium theory, in the long run the carbon sequestration rate will level off (Figure A3.1). 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 equilibrium is reached. Vellinga, Van den Pol-Van Dasselaar and Kuikman (2004) calculated sequestration rates of 40 kg carbon per hectare in 200-year old grasslands. This sequestration rate is much lower than the 600–800 kg reported by Soussana *et al*. (2007) and Soussana, Tallec and Blanfort (2009). At this moment, the equilibrium

Figure A3.1
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 carbon per hectare per year. After arable land as had a 200 year life, emission of soil carbon is still 30 kg carbon per hectare per year. These calculations are based on Vellinga, Van den Pol-Van Dasselaar and Kuikman (2004).

approach is the most common in this type of research and therefore should be considered the preferred method.

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 communication) found literature indicating significant and long-lasting depletion of soil organic carbon on arable land. The average carbon loss was about 400 kg per hectare per year for conventional agriculture. Leip *et al.* (2010) base their approach on the work of Soussana *et al.* (2007) and Soussana, Tallec and Blanfort (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, Wensem, and Oenema (2009), who found a constant soil organic matter content on arable land in the Netherlands. Vellinga, Van den Pol-Van Dasselaar and Kuikman (2004) calculated carbon losses of 30 kg per hectare 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 carbon dioxide, 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 nature 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 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 hectare per year is used for permanent pastures without grassland renovation, with an assumed minimum and maximum rates of between 0 and 228 kg per hectare per year, respectively. In the case of grassland renovation, the sequestration rates are lower (Table A.3). 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.

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 A.4.

Table A3.1: 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)

Table A3.2: Losses of Nitrogen, 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	12 466	1.90	890

Note: Emissions from changing carbon stocks, including grassland renovation 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 hectare per year is used, with a minimum rate of 0 and a maximum rate of 60 kg per hectare per year. Extremely high rates in the range of 600 to more than 1 000 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.

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Appendix 4
Oxidation of peat

The most recent reference for oxidation of peat is Joosten (2009), and this section on 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 from peat fires are not included. Default emission factors for carbon dioxide are derived from Couwenberg (2009) or based on interpolations and educated estimates. Only emissions from drained peatlands are included. Carbon dioxide and methane fluxes in pristine peatlands are not addressed, which is in line with the UNFCCC philosophy.

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

Table A4.1: Default values used for CO_2 emissions from drained peat soils (in tonnes 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 figures.

* 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.

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Appendix 5
Rice cultivation

Methane (CH_4) is emitted during rice cultivation. 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: CH_4-rice = EF CH_4rice * cultivation period

EF = emission factor, expressed in kg CH_4 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 shall be factored in.

$$EFCH_4rice = EFc * SFw * SFp * SFo$$

where:

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 A.5.12 (IPCC, 2006)

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 A.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 per hectare

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 A.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 nitrogen content of manure is expressed in g/kg (or kg/tonne). The value is set at 4 kg/tonne. It is assumed that rice straw is incorporated more than 30 days before a new crop is planted.

Table A5.1 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 1 000 to 6 000 kg of dry matter per hectare.

Table A5.1: 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	1 000	1.162112
0.29	2 000	1.309808
0.29	3 000	1.446727
0.29	4 000	1.575171
0.29	5 000	1.696711
0.29	6 000	1.812478

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Appendix 6
Anaerobic storage

In palm oil production, the palm oil mill effluent 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 *et al.* (2006), giving an average figure of 6.5 kg of methane per tonne of input of fresh fruit bunches.

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Appendix 7
Transport distances

REFERENCE UNITS

The reference unit for transport is directly related to those units that are used as outputs of crop production, processing and feed milling per 1 000 kg of product.

Transport is considered to be germane to every step in the feed production chain. It can involve transport of crop products from farm fields directly to the livestock farm, or their further transport to an industrial processing facility, for example, when 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. The final unit used to calculate transport is the transport of 1 000 kg of product over 1 kilometre with transport modalities expressed as T_1 - T_x (tonne-km). A third defining factor is related to the transport efficiency, which includes among other things, the loading of the means of transport and the quality of the roads.

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

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 (e.g. trains, boats). 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/tonne-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.

TRANSPORT DISTANCES AND MODALITIES

Place of departure and of arrival

In case 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 standardized 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 endproducts within a country is based on a standardized inland transport distance.

Transport from country Departure (D) to Arrival (A) 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.

Situation 2: Crop in country D, processing, feed mill and farm in A
- When the crop is transported from country D to A, it goes 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.

Figure A7.1
Transport scheme for situation 1 and 2 with international truck transpor

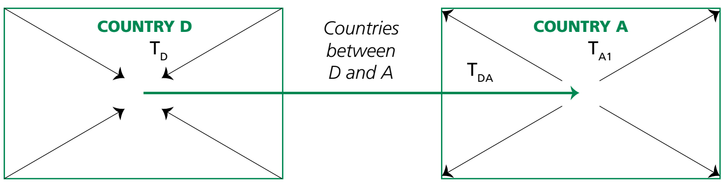
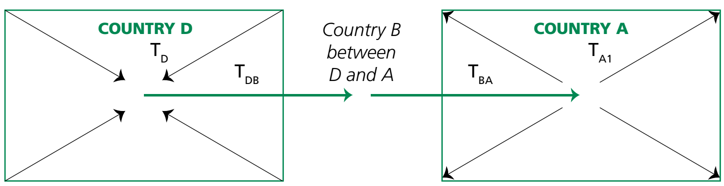


Figure A7.2
Transport scheme for situation 3 with international truck transport



- In the case of inland transport in country A from processing to feed mill and from feed mill to farm, the 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, it goes 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}.

The approach for between-country transport by truck is summarized in Table A.7.1.

Transport from country D to A by inland ship

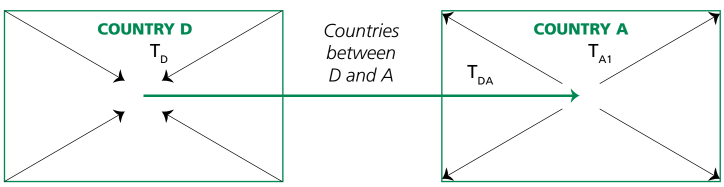
Situation 1: Crop and processing in the same country, feed mill and farm in A

- 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.

Table A7.1: 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	

Figure A7.3
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}.

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 transports by inland ship is summarized in Table A7.2.

Figure A7.4
Transport scheme for situation 3A and 3B with international inland ship transport

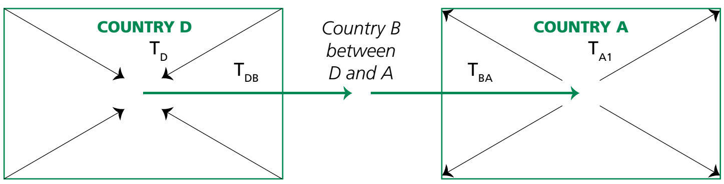


Table A7.2: Transport distances from country A to NL with transport to NL by inland waterway.

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	

Figure A7.5
Transport scheme for situation 1 and 2 with international sea ship transport

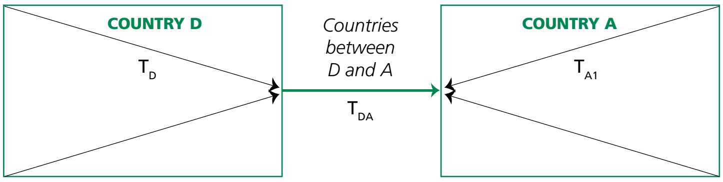
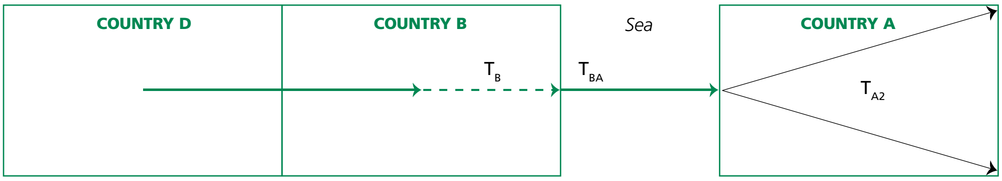


Figure A7.6
Transport scheme for situation 3A with international sea ship transport



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.

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}.

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}.

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 A7.7
Transport scheme **for situation 3B with international sea ship transport**

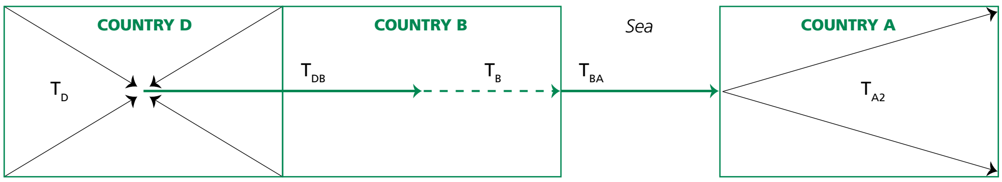


Figure A7.8
Transport scheme **for situation 3C with international sea ship transport**

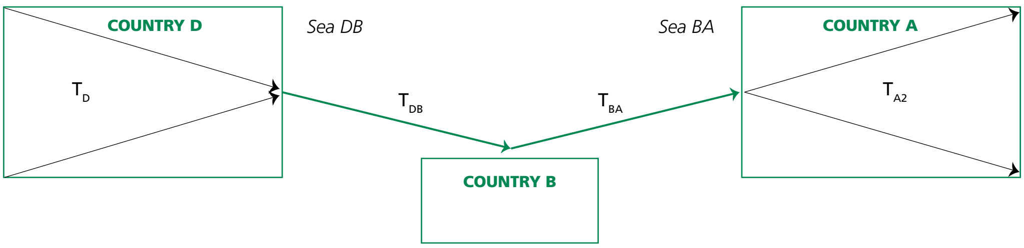


Table A7.3: transport distances from country d to a in case of transport to a by sea ship.

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 approach for between-country transport by sea ship is summarized in Table A.9.

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.

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. Should there be any country where trains are used as a transport modality, 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 harbor to harbor are collected on Portworld's online tool (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 km) is provided. When Portworld does not provide a port for any given country, then the transport distance can be computed by choosing another port, (preferably the capital of the country) and using the online distance calculator of Sea Rates (http://www.searates.com/reference/portdistance/). This calculator converts the distance in nautical miles was into km 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 to imitate the inland vessel waterways. A map of European inland vessel waterways can be found at Bureau Voorlichting Binnenvaart (http://www.bureauvoorlichtingbinnenvaart.nl).
- Distances travelled by ship in **short sea voyages** can be computed, again, by using Portworld's online tool. 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.

Table A7.4: 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				
Sea ship	19668		9684	5124	-
Inland shipD			0		
Airplane					
LorryA	19		19	19	
TrainA					
Inland shipA	108		108	108	

Note: The letters D and A indicate the country of departure and the country of arrival.

Transport modalities

Inlands vessels can carry a volume of 500–5 000 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 tonnes (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 include Handy size vessels with a carrying capacity of from 20 000 to 35 000 tons and that have access to a large number of ports; Panamax vessels with a carrying capacity of 50 000 – 80 000 tonnes; and Cape size vessels with a carrying capacity of 100 000 to 300 000 tonnes that can only access only the largest seaports and cannot pass through the Panama Canal (Bradley *et al.*, 2009).

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 between Australia and the Netherlands for example, sea transport plays an important role. The transport in Australia brings 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.

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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 crop production and processing in Kenya: A wheat and maize case study
3. The concentrate feed value chain in Uganda and Kenya
4. Animal feed supply chain for the poultry sector:A North American case study

Figure A8.1
Fodder production and marketing chain in Kenya. A Napier and Rhodes grass case study

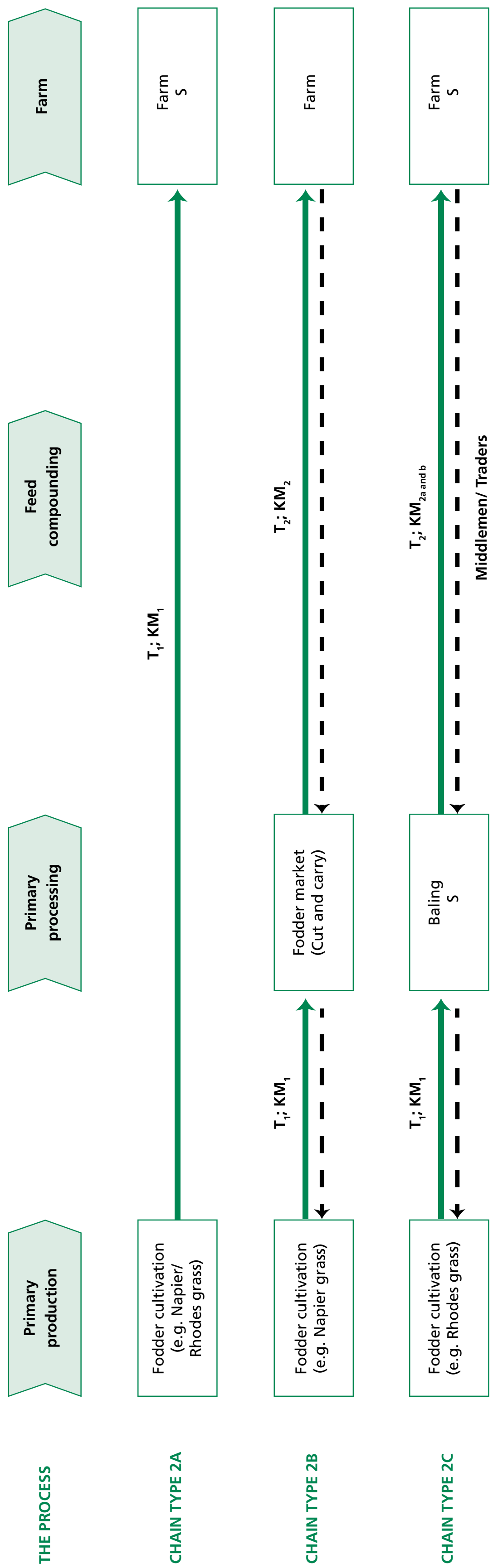

Table A8.1: Description of the fodder marketing chain in Eastern Africa

Chain type	Description of the fodder marketing chain in Kenya
Chain type 2A	This chain is common on smallholder farms. Planted fodder (Napier grass or Rhodes grass) 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). The distance (km_1) on farms is from 100 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 pulverizers. Storage (S) on farms lasts from to 3 days. About 90 percent of Napier grass and 10 percent of Rhodes grass 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 the same as in chain type 2A. About 10 percent of Napier grass passes through this chain
Chain type 2C	This chain commonly involves medium to large farms that cultivate grass fodder (acres) mainly for sale. It involves Rhodes grass (RG) only, which is harvested and baled on farms. Bales of Rhodes grass are transported (T_1) from fields for storage on farm (– 200 to -1 000m). Bales of Rhodes grass 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 1 000 to 5 000 bales and transport such bales up to 350 km away using 14-tonne 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 Rhodes grass passes through this chain.

Figure A8.2
The food-feed crops production and processing in Kenya. A wheat and maize case study

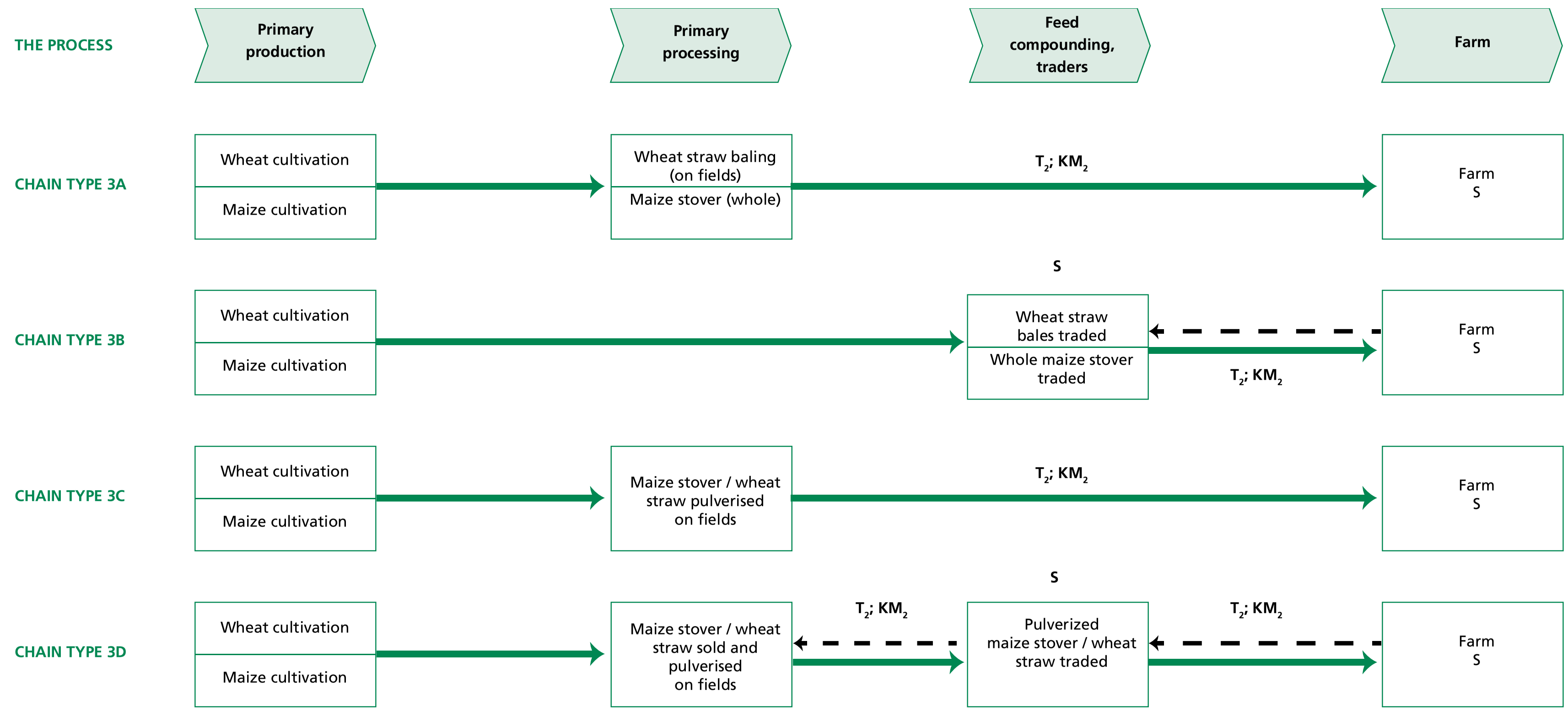

Table A8.2: Description of the maize stover and wheat straw supply chains in Kenya

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 and maize stover 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 pulverizes. Approximately 60 percent maize stover and 15 percent wheat straw 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 maize stover and 70 percent wheat straw 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 maize stover and wheat straw 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 maize stover and 5 percent of wheat straw passes through this chain.

Figure A8.3
Concentrate feed production and supply chains in Eastern Africa

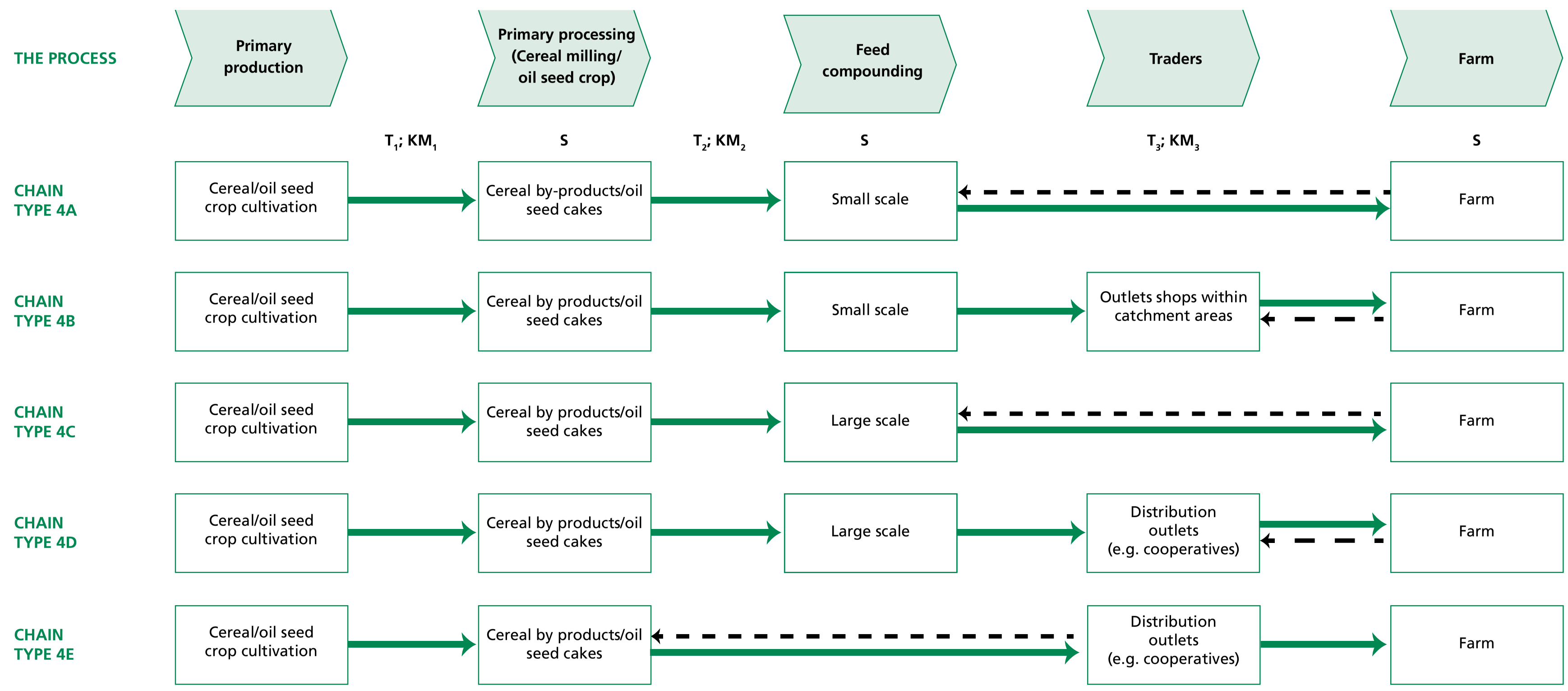

Table A8.3: Description of the concentrate feed supply chains in East Africa

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 their own premises for storage (S; 7 to 17 days). T_1 ranges from 1 to 20 km using mainly 7-tonne trucks. The processing companies source and transport (T_2) raw materials (cereals and oilseeds) from producers. Raw materials are stored (S) for periods of from 7-to 30 days. T_2 ranges from 50 to 250 km using large, 14-tonne trucks. Small-scale dealers manually mix and package between 2 and 10 tonnes 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 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-tonne 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 compounded feeds 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- to 14-tonne 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-tonne trucks. Compounded feeds are delivered to large-scale farms upon order. T3 ranges from 50 to 200 km using 7 to 10-tonne 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 compounded feeds pass 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 compounded feeds to a range of merchants (e.g. dairy cooperatives, agrovet shops and general stores). T_1 and T_2 are the same. T_3 ranges from 50 to 100 km using 7- to 10-tonne tracks. Approximately 35 percent of compounded feeds 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. The modes of transport and distances T_1, T_2 and T_3 are the same as in chain type 4D.

Figure A8.4

Animal feed supply chain for poultry sector – A North America case study

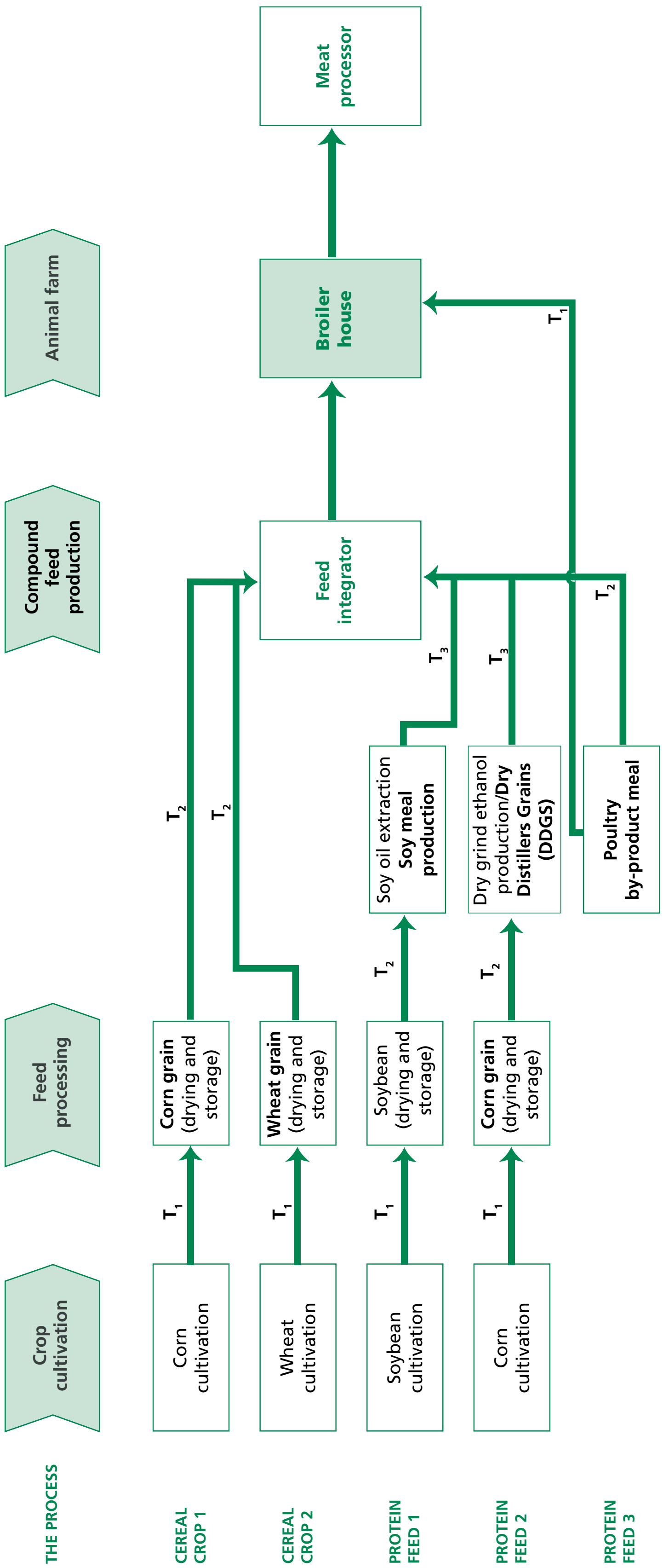

Table A8.4: Animal feed supply chain description for US Broiler operations

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 a 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 (T_1) 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 (T_2) by heavy-duty trucks over a distance of 40 miles to the feed integrator, which is located on the site of the 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 a minimum 5 percent of residue (approximately) 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 (T_1) and elevator to feed integrator (T_2) 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 (T_1) and elevator to oil extraction plant (T_2) 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 (T_3) over a distance of 40 miles to the feed integrator.
Protein feed 2 (DDGs)	Dry distillers grains and soluble (DDGS) is a co-product from dry grind corn ethanol production and similar to soybean meal, it is transported using heavy heavy-duty trucks (T_3) over a distance of 40 miles from dry grind ethanol plants to the feed integrator.
Protein feed 3 (poultry by-product meal)	Poultry by-product meal is generated on the site of the broiler feeding operation during meat processing. Therefore, transport distances (T_1 and T_2) 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/).

The Figure A8.4 above describes the supply chain for various animal feeds in industrialized feeding systems for the poultry sector (specifically US Broiler industry) in North America. Typical feed composition data (Table A8.5) is obtained from AGRI STATS (www.agristats.com) for 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 A8.6.

Table A8.5: US Broiler operations – Feed ingredient usage vs. performance

	Days to 6 pounds	% Mortality	Feed ingredients								
			% Wheat	% CF Meat Products	% DDGS	% soya bean meal	% Syn Lysine	% DL Methionine	% Syn Threonine	% Added Fat	% Corn (by difference)
weighted average	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.

Table A8.6: 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

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